United States
Environmental Protection
Agency

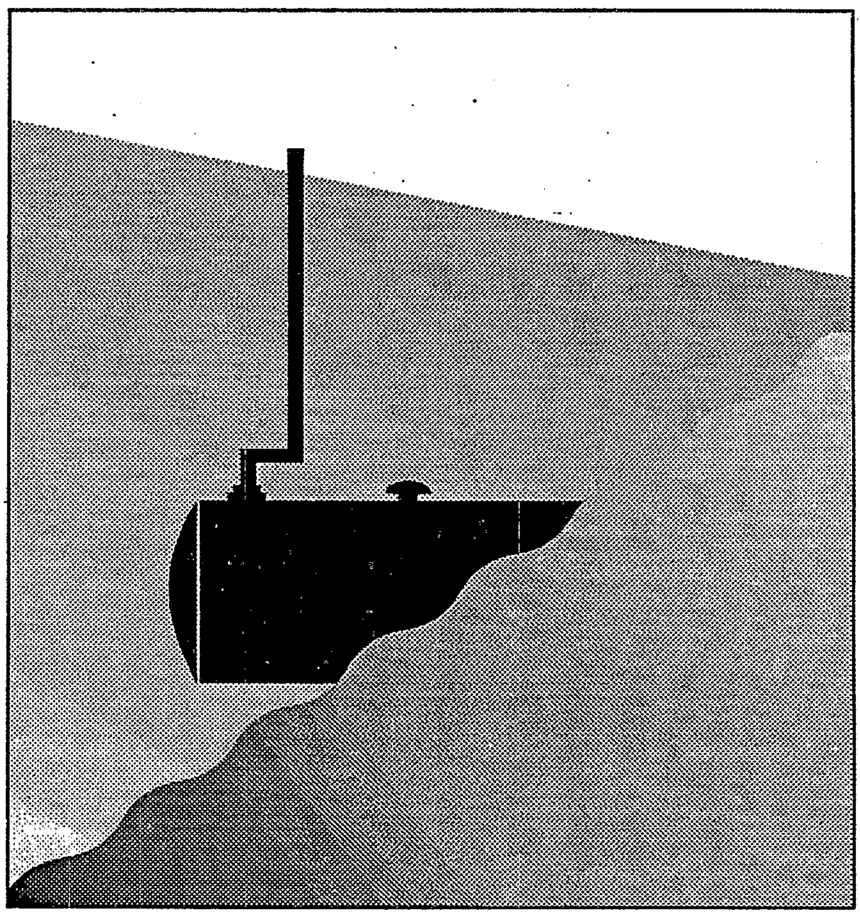
Solid Waste And
Emergency Response/
Research and Development

EPA/530/UST-90/005
March 1990

EPA

Standard Test Procedures for Evaluating Leak Detection Methods:

Nonvolumetric Tank Tightness Testing Methods



Printed on Recycled Paper

Standard Test Procedures for Evaluating Leak Detection Methods: Nonvolumetric Tank Tightness Testing Methods

Final Report

U.S. Environmental Protection Agency
Office of Underground Storage Tanks

March 1990

FOREWORD

How to Demonstrate That Leak Detection Methods Meet EPA's Performance Standards

The Environmental Protection Agency's (EPA's) regulations for underground storage tanks require owners and operators to check for leaks on a routine basis using one of a number of detection methods (40 CFR Part 280, Subpart D). In order to ensure the effectiveness of these methods, EPA set minimum performance standards for equipment used to comply with the regulations. For example, after December 22, 1990, all tank tightness testing methods must be capable of detecting a 0.10 gallon per hour leak rate with a probability of detection of at least 95% and a probability of false alarm of no more than 5%. It is up to tank owners and operators to select a method of leak detection that has been shown to meet the relevant performance standards.

Deciding whether a method meets the standards has not been easy, however. Until recently, manufacturers of leak detection methods have tested their equipment using a wide variety of approaches, some more rigorous than others. Tank owners and operators have been generally unable to sort through the conflicting sales claims that are made based on the results of these evaluations. To help protect consumers, some state agencies have developed mechanisms for approving leak detection methods. These approval procedures vary from state to state, making it difficult for manufacturers to conclusively prove the effectiveness of their method nationwide. The purpose of this policy is to describe the ways that owners and operators can check that the leak detection equipment or service they purchase meets the federal regulatory requirements. States may have additional requirements for approving the use of leak detection methods.

EPA will not test, certify, or approve specific brands of commercial leak detection equipment. The large number of commercially available leak detection methods makes it impossible for the Agency to test all the equipment or to review all the performance claims. Instead, the Agency is describing how equipment should be tested to prove that it meets the standards. Conducting this testing is left up to equipment manufacturers in conjunction with third-party testing organizations. The manufacturer will then provide a copy of the report showing that the method meets EPA's performance standards. This information should be provided to customers or regulators as requested. Tank owners and operators should keep the evaluation results on file to satisfy EPA's record keeping requirements.

EPA recognizes three distinct ways to prove that a particular brand of leak detection equipment meets the federal performance standards:

1. Evaluate the method using EPA's standard test procedures for leak detection equipment;

2. Evaluate the method using a national voluntary consensus code or standard developed by a nationally recognized association or independent third-party testing laboratory; or,

3. Evaluate the method using a procedure deemed equivalent to an EPA procedure by a nationally recognized association or independent third-party testing laboratory.

The manufacturer of the leak detection method should prove that the method meets the regulatory performance standards using one of these three approaches. For regulatory enforcement purposes, each of the approaches is equally satisfactory. The following sections describe the ways to prove performance in more detail.

EPA Standard Test Procedures

EPA has developed a series of standard test procedures that cover most of the methods commonly used for underground storage tank leak detection. These include:

1. "Standard Test Procedures for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods"

2. "Standard Test Procedures for Evaluating Leak Detection Methods: Nonvolumetric Tank Tightness Testing Methods"

3. "Standard Test Procedures for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems"

4. "Standard Test Procedures for Evaluating Leak Detection Methods: Statistical Inventory Reconciliation Methods"

5. "Standard Test Procedures for Evaluating Leak Detection Methods: Vapor-Phase Out-of-tank Product Detectors"

6. "Standard Test Procedures for Evaluating Leak Detection Methods: Liquid-Phase Out-of-tank Product Detectors"

7. "Standard Test Procedures for Evaluating Leak Detection Methods: Pipeline Leak Detection Systems"

Each test procedure provides an explanation of how to conduct the test, how to perform the required calculations, and how to report the results. The results from each standard test procedure provide the information needed by tank owners and operators to determine if the method meets the regulatory requirements.

The EPA standard test procedures may be conducted directly by equipment manufacturers or may be conducted by an independent third party under contract to the manufacturer. However, both state agencies and tank owners typically prefer that the evaluation be carried out by an independent third-party in order to prove compliance with the regulations. Independent third-parties may include consulting firms, test laboratories, not-for-profit research organizations, or educational institutions with no organizational conflict of interest. In general, EPA believes that evaluations are more likely to be fair and objective the greater the independence of the evaluating organization.

National Consensus Code or Standard

A second way for a manufacturer to prove the performance of leak detection equipment is to evaluate the system following a national voluntary consensus code or standard developed by a nationally recognized association (e.g., ASTM, ASME, ANSI, etc.). Throughout the technical regulations for underground storage tanks, EPA has relied on national voluntary consensus codes to help tank owners decide which brands of equipment are acceptable. Although no such code presently exists for evaluating leak detection equipment, one is under consideration by the ASTM D-34 subcommittee. The Agency will accept the results of evaluations conducted following this or similar codes as soon as they have been adopted. Guidelines for developing these standards may be found in the U.S. Department of Commerce "Procedures for the Development of Voluntary Product Standards" (FR, Vol. 51, No. 118, June 20, 1986) and OMB Circular No. A-119.

Alternative Test Procedures Deemed Equivalent to EPA's

In some cases, a specific leak detection method may not be adequately covered by EPA standard test procedures or a national voluntary consensus code, or the manufacturer may have access to data that makes it easier to evaluate the system another way. Manufacturers who wish to have their equipment tested according to a different plan (or who have already done so) must have that plan developed or reviewed by a nationally recognized association or independent third-party testing laboratory (e.g., Factory Mutual, National Sanitation Foundation, Underwriters Laboratory, etc.). The results should include an accreditation by the association or laboratory that the conditions under which the test was conducted were at least as rigorous as the EPA standard test procedure. In general this will require the following:

1. The evaluation tests the system both under the no-leak condition and an induced-leak condition with an induced leak rate as close as possible to (or smaller than) the performance standard. In the case of tank testing, for example, this will mean testing under both 0.0 gallon per hour and 0.10 gallon per hour leak rates. In the case of ground-water monitoring, this will mean testing with 0.0 and 0.125 inch of free product.

2. The evaluation should test the system under at least as many different environmental conditions as the corresponding EPA test procedure.

3. The conditions under which the system is evaluated should be at least as rigorous as the conditions specified in the corresponding EPA test procedure. For example, in the case of volumetric tank tightness testing, the test should include a temperature difference between the delivered product and that already present in the tank, as well as the deformation caused by filling the tank prior to testing.

4. The evaluation results must contain the same information and should be reported following the same general format as the EPA standard results sheet.

5. The evaluation of the leak detection method must include physical testing of a full-sized version of the leak detection equipment, and a full disclosure must be made of the experimental conditions under which (1) the evaluation was performed, and (2) the method was recommended for use. An evaluation based solely on theory or calculation is not sufficient.

ACKNOWLEDGMENTS

This document was written by Jairus D. Flora Jr., Ph.D., Karin M. Bauer, and H. Kendall Wilcox, Ph.D., for the U.S. Environmental Protection Agency's Office of Underground Storage Tanks (EPA/OUST) under Contract No. 68-01-7383. The Work Assignment Manager for EPA/OUST was Thomas Young and the EPA/OUST Project Officer was Vinay Kumar. Technical assistance and review were provided by the following people:

Russ Brauksieck - New York Department of Environmental Conservation
Tom Clark - Minnesota Pollution Control Agency
Allen Martinets - Texas Water Commission
Bill Seiger - Maryland Department of Environment

American Petroleum Institute
Leak Detection Technology Association
Petroleum Equipment Institute

CONTENTS

SECTION 1

INTRODUCTION

1.1 BACKGROUND

The regulations on underground storage tanks (40 CFR Part 280, Subpart D) specify performance standards for leak detection methods that are internal to the tank. For tank tightness testing, the tests must be capable of detecting a leak of 0.10 gallon per hour with a probability of (at least) 95%, while operating at a false alarm rate of 5% or less.

A large number of test devices and methods are reaching the market, but little evidence is available to support their performance claims. Advertising literature for the methods can be confusing. Owners and operators need to be able to determine whether a vendor's tank tightness test method meets the EPA performance standards. The implementing agencies (state and local regulators) need to be able to determine whether a tank facility is following the UST regulations, and vendors of tank tightness test methods need to know how to evaluate their systems.

Presently, there are two categories of tank tightness testing methods on the market: (a) volumetric testing methods, which measure directly the leak rate in gallons per hour, and (b) nonvolumetric testing methods, which report only the qualitative assessment of leaking or not leaking.* These two testing methods require different testing and statistical analysis procedures to evaluate their performance. The protocol in this document should be followed when the method is a nonvolumetric one. The evaluation of the performance of volumetric tank tightness testing methods is treated in a separate protocol. To simplify the terminology throughout this document, nonvolumetric tank tightness testing methods are referred to as tank tightness testing methods.

The use of tracers for leak detection purposes is one of the approaches permitted by the regulations. While the approach has been classified by some as an external (out-of-tank) method, it has several characteristics that are common to nonvolumetric internal methods. In particular, the type and amount of data collected and the statistical analysis of the data are nearly identical to those used for other nonvolumetric methods. Also, the tracer is internal to the tank, although the sensors are external to the tank. This protocol includes

* Conceivably, a "nonvolumetric method" could utilize some measure of volume change, but in a qualitative manner.

procedures for determining whether the performance of a method using tracers meets the performance requirements for tank tightness testing.

1.2 OBJECTIVES

The objectives of this protocol are twofold. First, it provides a procedure to test tank tightness testing methods in a consistent and rigorous manner. Secondly, it allows the regulated community and regulators to verify compliance with regulations.

This protocol provides a standard method that can be used to estimate the performance of a tank tightness test method. Tank owners and operators are required to demonstrate that the method of leak detection they use meets the EPA performance standards of operating at (no more than) a 5% false alarm rate while having a probability of detection of (at least) 95% to detect a leak of 0.10 gallon per hour. This demonstration must be made no later than December 22, 1990. The test procedure described in this protocol is one example of how this level of performance can be proven. The test procedure presented here is specific, based on reasonable choices for a number of factors. Information about other ways to prove performance is provided in the Foreword of this document.

This protocol does not address the issue of safety testing of equipment or operating procedure. The vendor is responsible for conducting the testing necessary to ensure that the equipment is safe for use with the type of product being tested.

1.3 APPROACH

In general, the protocol calls for using the method on a tight tank under no-leak conditions and under induced-leak conditions, producing leak rates of 0.10 gallon per hour or less. The nonvolumetric test method being evaluated determines whether the tank is leaking or not during each test. This reported result is compared with the actual condition of the tank during testing to estimate the false alarm rate and probability of detection. Once these probabilities have been estimated, the estimates are compared with the EPA performance standards to determine whether the method meets the EPA performance standards.

The companion evaluation protocol for volumetric tank tightness tests ("Standard Test Procedures for Evaluating Leak Detection Methods: Volumetric Tank Tightness Testing Methods," March 1990) requires testing under different conditions that simulate interferences likely to be encountered in actual test conditions. For volumetric methods these include adding product at temperatures different from that of the product in the tank and filling the tank prior to some of the tests. Such tests address temperature effects and tank deformation effects that can affect measurements of level or volume change. If the nonvolumetric method being tested uses physical principles that might be affected by temperature or tank deformation effects, then the test series should account for these. If the evaluator determines that the physical principles of the test are not affected by these variables, then the temperature and tank deformation parameters need not be varied during the test series. Conversely, if the evaluator determines that other sources of interference (e.g., background vapor concentrations, external acoustical noise) might affect the performance of the method, then conditions to test for these effects must be included in the design. For purposes of illustration, this protocol assumes that temperature and tank deformation effects are important, unless the evaluator determines otherwise.

Some nonvolumetric test methods use more than one approach to detecting a leak. In this event, each approach must be tested and evaluated to determine whether or under what conditions the system meets the EPA performance standards. For example, some nonvolumetric methods rely on detection of water incursion during the test to detect a leak in the presence of a high ground-water level. If this is part of the standard operating procedure, the water detection sensor needs to be evaluated as part of the evaluation procedure. In addition to determining the performance of the water detection sensor as a leak indicator, the performance parameters (minimum detectable water level and minimum detectable level change) must be related to the size of the test tank to determine whether the water detector could sense water incursion at the rate of 0.10 gallon per hour under the test conditions with a probability of at least 95%, while operating at a false alarm rate of 5% or less. That is, each mode of leak detection must be evaluated and compared to the EPA performance standards.

It is emphasized that testing must include conditions designed to test the ability of the method to correctly detect a leak of the specified size (0.10 gallon per hour) in the presence of sources of interference. Sources of interference, such as product temperature changes, that do not affect the physical principles of operation of a method do not need to be included in the testing. However, the evaluating organization must consider what alternative sources of interference might affect the operation of the method and must include tests to determine whether the method successfully overcomes these sources of interference. The testing conditions should be designed to cover the majority of cases; that is, interference conditions as extreme as would be encountered in approximately 75% of real world tests. Testing need not include extreme cases that are rarely encountered.

This document addresses two general types of nonvolumetric tank tightness testing methods. One type is internal to the tank. A probe with sensors is placed in the tank and senses whether some physical characteristic associated with a leak is present. The second type introduces a tracer material into the tank. The method then detects leaks by monitoring the exterior of the tank for the presence of the tracer. Since the only source of the tracer is from the tank, the presence or absence of tracer in the external environment is taken to be conclusive evidence that the tank is either leaking or tight.

The technical requirements for the use of tracers are described in the release detection section of the regulations on vapor monitoring (40 CFR 280.43[e]). The major requirements which must be considered in evaluating the tracer method are therefore:

1. The backfill where the sampling is conducted must be porous enough to readily allow diffusion of vapors to the sensor.

2. The tracer must be volatile enough to produce vapor levels which are detectable by the monitoring device.

3. Ground water, rain, or soil moisture must not interfere with the operation of the monitor.

4. Background contaminations must not interfere with the detection of releases from the tank.

5. The number and positioning of the monitoring wells must be optimized for the detection of leaks from any part of the system.

Although these requirements are for continuous vapor monitoring devices, they apply to the use of a tracer technique when it is used as a tank tightness test. Accordingly, the present protocol takes these factors into account when evaluating tracer techniques.

Two types of tracer techniques have been developed: those which add tracer to the fuel and can perform a leak test with product in the tank; and those which place a gas into an empty tank. The former typically uses halogenated hydrocarbons as the tracer material while the latter may use sulfur hexafluoride or helium as the tracer material. In both cases, the tracer is placed in the tank and samples are collected outside the tank. Depending upon the specific method, or variation thereof, the time to detect a leak may vary from a few minutes to several days. Estimates of the leak rate can be obtained from methods which add tracer to the product, for example, by using a spiked sample to produce a known concentration which can be compared to the observed concentration of tracer found at a leaking tank. Methods which use gases in an empty tank are usually limited to pass/fail conclusions since it is difficult to relate the loss of a gas through a hole to an equivalent amount of product through the same hole. The tracer techniques may also be used to test the product lines or any other part of the system which is exposed to the tracer.

The application of a single protocol to the various tracer techniques may present some practical problems. The use of a tracer in an actual test situation will contaminate the environment with the tracer, rendering the site unsuitable for replicate testing, at least, for some period of time. For methods which rely on halogenated compounds, it may be possible to use several different tracers at the same site. For methods which rely on a single tracer, the tracer must either be removed from the site using techniques such as forced ventilation, another site must be selected for the replicate testing tracer, or the replicate tests must wait until the tracer has dissipated. Since several replications are required for satisfactory statistical analysis, the procedures can prove to be cumbersome.

It is recognized that new nonvolumetric methods may be developed after this document is published. These new methods could be based on different physical principles from those employed by currently available methods. The detailed test methods described in this document may not be entirely appropriate for new methods in that they may not address these new approaches. To allow for such contingencies, it will be the responsibility of the evaluating organization to determine whether a new method can be evaluated with the current protocol or whether the new method has aspects that require additional or different testing. In the latter case, it is the responsibility of the evaluating organization to devise an appropriate test series and conduct the testing needed to evaluate the method in a manner such that its performance can be compared to the EPA performance standards. See the Foreword for a description of alternative approaches.

1.4 EFFECTS OF HIGH GROUND-WATER LEVEL

The ground-water level is a potentially important variable in tank testing. Ground-water levels are above the bottom of the tank at approximately 25% of the tank sites nationwide, with higher proportions in coastal regions. Also, tidal effects may cause fluctuations in the ground-water level during testing in some coastal regions. If the ground-water level is above the bottom of the tank, the water pressure on the exterior of the tank will tend to counteract the product pressure from the inside of the tank. If the tank has a leak (hole) below the ground-water level, the leak rate in the presence of the high ground-water level will be less than it would be with a lower ground-water level. In fact, if the ground-water level is high enough, water may intrude into the tank through the hole.

The means by which the method deals with the ground-water level must be documented. A method that does not take the ground-water level into account is not adequate. If the ground-water level is determined to be above the bottom of the tank, a method that tests in this situation must include a means of compensating for the high ground-water level. Acceptable means of compensating are to either ensure that the tank has an outward pressure throughout or that the groundwater exerts an inward pressure at all levels in the tank. If an alternative approach to compensating for ground-water effects is used, the evaluating organization must perform an engineering evaluation of the approach to ensure that it is adequate. If in doubt, the evaluating organization may require tests in addition to those detailed in this document.

1.5 ORGANIZATION OF THIS DOCUMENT

The next section presents the scope and applications of this protocol. Section 3 presents an overview of the approach, and Section 4 presents a brief discussion of safety issues. The apparatus and materials needed to conduct the evaluation are discussed in Section 5. The step-by-step procedure, adapted for two existing types of nonvolumetric test methods, is presented in Section 6. Section 7 describes the data analysis and Section 8 provides some interpretation of results. Section 9 describes how the results are to be reported.

Two appendices are included in this document. Definitions of some technical terms are provided in Appendix A. Appendix B presents a compendium of forms: a standard reporting form for the evaluation results, a standard form for describing the operation of the method, data reporting forms, and an individual test log. Appendix B thus forms the basis for a standard evaluation report.

SECTION 2

SCOPE AND APPLICATIONS

This document presents a standard protocol for evaluating nonvolumetric tank tightness testing methods. The protocol is designed to evaluate methods that test a tank at a specific point in time. The methods determine a yes or no answer to the question: "Is the tank leaking?" The nonvolumetric methods currently commercially available use some physical result from a leaking tank to make this determination. Some may use more than one characteristic of a leaking tank in making their determination. This protocol is designed to evaluate the method's ability to detect a leak of 0.10 gallon per hour with a probability of at least 95%, while operating at a false alarm rate of no more than 5%, as specified in the performance standard in the UST regulations.

The protocol also provides tests to determine the minimum water level that the method can detect. In addition, the protocol tests the ability of the water sensor to measure changes in the water level. These are evaluated over a range of a few inches in the bottom of the tank. The minimum water level and minimum water level change that the method can detect are converted to gallons using the geometry of the tank. From that, the minimum time it would take the sensor to detect a 0.10-gallon per hour leak is calculated. These tests are only performed if the method uses a water sensor to detect leaks in situations such as a high ground-water level.

The document also presents a protocol for evaluating tracer methods at actual tank installations. The protocol does not include laboratory testing of components such as vapor sensors. It is designed to be used for tracer methods that are applied to a tank at a specific point in time.

Subject to the limitations listed on the Results of U.S. EPA Standard Evaluation form (Appendix B), the results of this evaluation can be used to prove that a nonvolumetric tank tightness testing method meets the requirements of 40 CFR Part 280, Subpart D. The Results of USEPA Standard Evaluation form lists the limitations on the method. For example, a minimum time for the test may be required in order for the physical characteristic of a leak to be sensed or for the tracer to reach the sampling ports. The performance results are valid provided the test is conducted for at least the specified time.

SECTION 3

SUMMARY

The evaluation protocol for nonvolumetric test methods calls for conducting the testing on a tight tank. The organization performing the evaluation should have evidence that the tank used for testing is tight, independent of the system currently being tested. The evidence that the tank is tight may consist of any of the following:

1. At least three automatic tank gauging system (ATGS) records within a 3-month period with inventory and test modes indicating a tight tank.

2. A tank tightness test by another test method in the 6 months preceding testing that indicates a tight tank.

3. Continuous vapor or liquid monitoring system installed that indicates a tight tank.

Any of the above, verified by a tight test result on the initial test (trial run) of the method under investigation, constitutes acceptable evidence. This information should be reported on the data report form (see Appendix B).

The protocol calls for an initial test (trial run) under stable conditions to ensure that the equipment is working and that there are no problems with the tank, associated piping, and the test equipment. If the tank fails the trial run test, however, then testing should not proceed until the problem is identified and corrected. Only if the evaluating organization has strong evidence that the tank is tight, should testing proceed.

The tank tightness testing equipment is installed at the tank site to be tested following the method's standard operating procedure. A minimum of 21 independent tests of the tank under the no-leak condition are performed. The results of these tight tank tests will be used to estimate the false alarm rate, P(FA). In addition, induced leaks at rates not to exceed 0.10 gallon per hour are simulated. Again, a minimum of 21 independent tests are performed with these induced leaks. The results of these tests will be used to estimate the probability of detecting a leak of the magnitude used, P(D). The simulation condition (tight tank or induced leaks) is kept blind to the vendor.

If sources of interference are to be evaluated, test conditions including these interferences are set up in a balanced experimental design. The conditions that may interfere with the method are applied to both tight and induced leak tests. The order of the tests is randomized to ensure that the conditions are kept blind to the vendor. The order of both the interfering conditions (if used) and the leak conditions are randomized. The proportion of tests under the tight tank condition that incorrectly indicate a leak is used to estimate the probability of a false alarm, while the proportion of induced leak tests correctly identified is used to estimate the probability of detection. Thus, each performance parameter, P(FA) and P(D), is estimated based on at least 21 tests.

For tracer methods, the protocol calls for the use of the method on a tank environment which is representative of a typical UST installation. It is not necessary for the tank to be in service to be acceptable for the evaluation process. The type of backfill around the tank, however, should be known and should be either sand, pea gravel, crushed rock, or other material which is commonly used as backfill material. If the monitoring is conducted in areas other than the backfill, the characteristics of the soil at the sampling location should also be known.

The testing of a nonvolumetric method based on tracer technology also involves a minimum of 42 tests. At least 21 tests are done under the tight tank condition and are used to estimate the probability of a false alarm. At least 21 tests are done with an induced or simulated leak and are used to estimate the probability of detection. As before, if interfering conditions are to be incorporated into the experimental design, these are established for tests in a random order. To estimate P(FA), the tracer is introduced into the product in the tank. After mixing and after the appropriate waiting time determined by the method's standard operating procedure has elapsed, the sample ports are sampled to determine if the tracer is detected. False alarms could occur if tracer is accidentally released during the process of adding it to the product or mixing it with the product. Consequently, the steps of adding the tracer and mixing the product in the tank should be repeated for each tight tank test.

For tracer methods, induced leaks are simulated by spiking the soil with a sample of nonregulated material containing the tracer. For example, a vegetable oil containing the tracer at the working concentration (e.g., 10 ppm) could be used to spike the soil at 0.10 gallon per hour. This would be continued for the specified test duration and the results recorded. To keep the process blind to the vendor, randomized samples of spiking solution, some with and some without tracer, could be used and spiking done for each test.

SECTION 4

SAFETY

This discussion does not purport to address all the safety considerations involved in evaluating leak detection equipment and methods for underground storage tanks. The equipment used should be tested and determined to be safe for the products it is designed for. Each leak detection method should have a safety protocol as part of its standard operating procedure. This protocol should specify requirements for safe installation and use of the device or method. This safety protocol will be supplied by the vendor to the personnel involved in the evaluation. In addition, each institution performing an evaluation of a leak detection device should have an institutional safety policy and procedure that will be supplied to personnel on site and will be followed to ensure the safety of those performing the evaluation.

Since the evaluations are performed on actual underground storage tanks, the area around the tanks should be secured. As a minimum, the following safety equipment should be available at the site:

- Two class ABC fire extinguishers
- One eyewash station (portable)
- One container (30 gallons) of spill absorbent
- Two "No Smoking" signs

Personnel working at the underground storage tank facility should wear safety glasses when working with product and steel-toed shoes when handling heavy pipes or covers. After the safety equipment has been placed at the site and before any work can begin, the area should be secured with signs that read "Authorized Personnel Only" and "Keep Out."

All safety procedures appropriate for the product in the tanks should be followed. In addition, any safety procedures required for a particular set of test equipment should be followed.

This test procedure only addresses the issue of the method's ability to detect leaks. It does not address testing the equipment for safety hazards. The manufacturer needs to arrange for other testing for construction standards to ensure that key safety hazards such as fire, shock, intrinsic safety, product compatibility, etc., are considered. The evaluating organization should check to see what safety testing has been done before the equipment is used for testing to ensure that the test operation will be as safe as possible.

SECTION 5

APPARATUS AND MATERIALS

5.1 TANKS

The evaluation protocol requires the use of an underground storage tank known to be tight. A second tank or a tank truck is needed to store product for the cycles of emptying and refilling, if required. As discussed before, the tank should have been tested and shown to be tight by any of the three methods described in Section 3. The tank should not have any history of problems. In addition, the protocol calls for an initial trial run with the test equipment under stable conditions. This test should indicate that the tank is tight; if it does not, there may be a problem with the tank and/or the test equipment that should be resolved before proceeding with the evaluation.

The tank facility used for testing is required to have at least one monitoring well. The primary reason for this is to determine the ground-water level. The presence of a ground-water level above the bottom of the tank would affect the leak rate in a real tank, that is, the flow of product through an orifice. The flow would be a function of the differential pressure between the inside and outside of the tank. However, in a tight tank with leaks induced to a controlled container separate from the environment, the ground-water level will not affect the evaluation testing. Consequently, it is not necessary to require that testing against the evaluation protocol be done in a tank entirely above the ground-water level. The monitoring well can also be used for leak detection at the site, either through liquid monitoring (if the ground-water level is within 20 feet of the surface) or for vapor monitoring.

Volumetric methods that measure volume or level changes of liquid product that occur as a result of a leak generally have worse performance as the size of the tank increases. However, the tank size does not affect the performance of existing nonvolumetric test methods to the same extent, since they are based on different physical principles. Consequently, it is not necessary to restrict the application of these test results to tanks with a volume equal to, or some arbitrary fraction larger than, the test tank. The evaluating organization should determine the appropriate size limit based on their testing, physical principles involved, and other available data, and state the limit on the results form (Appendix B). For example, tanks larger than 50,000 gallons have a different construction and geometry than the standard horizontal cylindrical tanks used for tanks up to this size. It may be the tank geometry and construction that impose limits rather than the size.

The test plan may require some testing with addition of product at a different temperature from that of the fuel already in the tank. This requirement is to verify that the method can accommodate the range of temperature conditions that routinely occur. The procedure requires that some tests begin by the tank being filled from about half full to the test level with fuel that is 5°F warmer than the product in the tank, and some tests using fuel 5°F cooler than the product in the tank. This procedure requires that some method of heating and cooling the fuel be provided, such as pumping the fuel through a heat exchanger, or by placing heating and cooling coils in the supply tank or tank truck before the fuel is transferred to the test tank. In the case of a tracer or acoustical method, the evaluating organization may eliminate the temperature and filling conditions if they are not relevant. The total number of tests to be performed remains the same, however. The temperature and filling conditions would obviously be inoperative if a gaseous tracer were to be used in an empty tank.

If the protocol or the method requires that the tank be filled or emptied a number of times, a second tank or a tank truck is needed to hold reserve product. A pump and associated hoses or pipes to transfer the product from the test tank to the reserve product tank or truck are also needed.

For tracer methods, the characteristics of a tank are less important. However, the test tank must be tight. The primary purpose of the tank is to provide an environment which is representative of typical tank installations. The tank is important for testing for false alarms. The procedure of adding and mixing tracer to the product is a potential source of false alarms from inadvertent release of the tracer into the environment.

5.2 TEST EQUIPMENT

The equipment for each tank test method will be supplied by the vendor or manufacturer. Consequently, it will vary by method. In general, the test equipment will consist of some method for monitoring the tank for the effect used by the method to indicate a leak. For tracer methods, the equipment will also include some method for introducing the tracer(s) into the tank or the backfill. The test equipment also typically includes instrumentation for collecting and recording the data and procedures for using the data to interpret the result as a pass or fail for the tank.

It is recommended that the test equipment for the method being tested be operated by trained personnel who regularly use the equipment in commercial tests. This should ensure that the vendor's equipment is correctly operated and will eliminate problems that newly trained or untrained individuals might have with the equipment. On the other hand, if the equipment is normally operated by the station owner, then the evaluating organization should provide personnel to operate the equipment after the customary training.

5.3 LEAK SIMULATION EQUIPMENT

The protocol calls for inducing leaks in the tank. The method of inducing the leaks must be compatible with the leak detection method being evaluated. The experimental design in Section 6 gives the nominal leak rates that are to be used. These leak rates refer to leak rates that would occur under normal tank operating conditions.

For volumetric methods, leak simulation can be accomplished by removing product from the tank at a constant rate, measuring the amount of product removed and the time of collection, and calculating the resulting induced leak rate. An explosion-proof motor can be used to drive a peristaltic pump head. The sizes of the pump head and tubing are chosen to provide the desired flow rates. A variable speed pump head can be used so that different flow rates can be achieved with the same equipment. The flow is directed through a rotameter so that the flow can be monitored and kept constant. One end of the tubing is inserted into the product in the tank. The other end is placed in a container.

Although this leak simulation approach may work for some nonvolumetric methods, most of these methods will require a method of simulating leaks that is adapted to their specific principle of operation. Examples of leak simulation methods for two nonvolumetric methods follow.

5.3.1 Leak Simulation Approach for Acoustical Methods

Two methods commercially available at the present time are based on acoustical signals generated when product flows through an orifice or when air is drawn through an orifice or hole in the tank that would allow it to leak. In order to simulate a leak condition for such a method, an orifice must be introduced into the tank so that product or air can flow through it during the test. A simulator of this type has been developed and is in the patent process. Its principle is described below. The size and location in the tank of the orifice must be determined so that it would represent a leak rate of 0.10 gallon per hour or less if it were present under normal operating conditions in the tank. One approach is to insert a pipe into the product in the tank through one of the openings in the top of the tank. The pipe has an orifice of the required size, allowing product to leak from the tank into the pipe, where it can be removed and measured. Likewise, if a partial vacuum is applied, air could be drawn into the tank through the orifice in the pipe. The orifice in the pipe can be calibrated by allowing product to flow into the pipe and measuring the flow rate.

5.3.2 Leak Simulation Approach for Tracer Methods

Two types of leak simulation equipment are required, depending upon the type of tracer technique in use. For methods which rely on detecting the loss from the tank of product containing tracer, the simulation equipment must be capable of delivering a liquid containing the tracer into the backfill close to the tank. The rate of delivery is used to control the volume of product introduced in the backfill. For methods which rely on detecting the loss of gaseous tracer from the tank, the simulation equipment must be capable of delivering the tracer gas into the backfill in known quantities so that the ability of the system to detect the tracer in the backfill can be evaluated. In either case, the amount of tracer introduced into the backfill should reflect the amount that would be released if the tank were leaking at a rate of 0.10 gallon per hour or less. To do this, the rate of delivery is used to control the amount of material introduced into the backfill. To simulate a zero leak rate, the tracer material is introduced into the test tank and mixed with the product as appropriate. However, a blank spike (without a tracer) would be introduced into the backfill.

Other nonvolumetric methods may use principles different from those of the methods in these examples. The evaluating organization will need to develop a method of leak simulation that is appropriate for a specific test method.

5.4 PRODUCT

The most common products in underground storage tanks are motor fuels, particularly gasoline and diesel fuel. Analysis of tank test data based on tanks containing a variety of products has shown no evidence of difference in test results by type of product, if the same size tank is considered. The only exception to this observation is that one tank test method did produce better results when testing tanks with pure chemicals (e.g., benzene, toluene, xylene) than when testing gasoline. This difference was attributed to better test conditions, longer stabilization times, and better cooperation from tank owners.

Any commercial petroleum product of grade number 2 or lighter may be used for testing, depending on the availability and restrictions of the test tanks. The choice of the product used is left to the evaluating organization, but it must be compatible with the test equipment.

5.5 TRACERS AND CARRIERS

When testing tracer methods, additional considerations apply. While use of petroleum products spiked with tracer would be ideal, the introduction of regulated products into the ground is prohibited in almost all situations. Therefore, for test purposes, the carrier used for liquid tracers should be of some nonregulated liquid such as mineral oil or vegetable oil. The concentration of tracer can be elevated in the carrier to reduce the actual volume of material to be introduced into the ground.

Direct injection of the tracer gas diluted in air can be used to evaluate methods which rely on the loss of tracer gases from the tank. The concentrations of tracers injected during the simulation process should approximate those contained in the tank during an actual test.

5.6 WATER SENSOR EQUIPMENT

The equipment to test the water sensor consists of a vertical cylinder with an accurately known (to ±0.001 inch) inside diameter. This cylinder should be large enough to accommodate the water sensor. Thus, it should be approximately 4 inches in diameter and 8 or more inches high. The probe is mounted so that the water sensor is in the same relation to the bottom of the cylinder as it would be to the bottom of a tank. In addition, a means of repeatedly adding a small measured amount of water to the cylinder is needed. This can be accomplished by using a pipette.

5.7 MISCELLANEOUS EQUIPMENT

As noted, the test procedure may require the partial emptying and filling of the test tank. One or more fuel pumps of fairly large capacity will be required to accomplish the filling in a reasonably short time. Hoses or pipes will also be needed for fuel transfer. Some test methods require some reserve product for calibration or establishing a specified product level. In addition, containers will be necessary to hold this product as well as that collected from the induced leaks. A variety of tools need to be on hand for making the necessary connections of equipment.

SECTION 6

TESTING PROCEDURE

The overall performance of the method is estimated by comparing the method's results, leaking or tight tank, to whether a leak was actually induced. Performance is measured over a variety of realistic conditions, including temperature changes and filling effects, if applicable. The evaluating organization is responsible for adding any other variables that may affect a specific nonvolumetric method. The range of conditions need not represent the most extreme cases that might be encountered, because extreme conditions can cause any method to give misleading results. If the method performs well under various test conditions, then it may be expected to perform well in the field.

The test procedures have been designed so that additional statistical analyses can be done to determine whether the method's performance is affected by the size of the leak or other factors. These additional analyses can only be done if the method makes a substantial number of mistakes so that the proportion of errors is between zero and one for some subsets of the data. Thus, they are only relevant if the method does not meet the performance standard.

For illustrative purposes, the basic test procedure introduces three main factors that may influence the test: size of leak, temperature effects, and tank deformation. The primary consideration is the size of the leak. The method is evaluated on its ability to detect leaks of specified sizes. If a method cannot detect a leak rate of 0.10 gallon per hour or if the method identifies too many leaks when no leak is induced, then its performance is not adequate.

A second consideration might be the temperature of the product added to fill a tank to the level needed for testing. Three conditions could be used: added product at the same temperature as the in-tank product, added product that is warmer than that already in the tank, and added product that is cooler. The temperature difference should be at least 5°F and should be measured and reported to the nearest degree F. For some methods, the temperature difference is needed to ensure that the method can adequately test under realistic conditions. The performance under the three temperature conditions can be compared to determine whether these temperature conditions have an effect on the method's performance. Note that some nonvolumetric methods require an empty tank or do not require a specific product level. If the principle of the nonvolumetric method is not affected by product temperature as determined by the evaluating organization, the test need not include this set of conditions, although the total number of tests must not be decreased.

Another consideration might be the tank deformation caused by pressure changes that are associated with product level changes. This consideration is addressed by requiring several empty-fill cycles. One test is conducted at the minimum time after filling specified by the test method. A second test follows without any change in conditions (except, possibly, leak rate). Comparison of the order of the test pairs can determine whether the additional time improves the method's performance. Again, if, as determined by the evaluating organization, the operating procedure of the method is not affected by pressure changes, this aspect of testing need not be included.

Nonvolumetric test methods operate on a wide variety of principles. Consequently, each method may have a different set of sources of interference related to its operating principle. The evaluating organization should consider possible sources of interference for the method being evaluated. The list of these sources considered and the conclusions reached should be reported. The considerations do not need to include the most extreme possible conditions, but should include conditions expected to be encountered in a large majority (e.g., 75%) of the normal tests cases.

In addition to varying these factors, environmental data are recorded to document the test conditions. These data may help to explain one or more anomalous test results.

The ground-water level is a potentially important variable in tank testing, and the system's means of dealing with it is to be documented. A system that does not determine the ground-water level and take it into account is not adequate. Ground-water levels are above the bottom of the tank at approximately 25% of underground storage tank sites nationwide, with higher proportions in coastal regions.

If the method uses water incursion to account for high ground-water levels, this protocol evaluates two aspects of the system's water sensing function: the minimum detectable water level and the minimum detectable change in water level. Together, these can be used with the dimensions of the tank to determine the ability of the system's water sensing device to detect inflows of water at various rates.

6.1 ENVIRONMENTAL DATA RECORDS

In general, the evaluation protocol requires that the conditions during the evaluation be recorded. In addition to all the testing conditions, the following measurements should be reported (see the Individual Test Log forms in Appendix B):

- ambient temperature, monitored hourly throughout each test
- barometric pressure, monitored hourly throughout each test
- weather conditions such as wind speed; sunny, cloudy, or partially cloudy sky; rain; snow; etc.
- ground-water level if above bottom of tank
- any special conditions that might influence the results

When testing tracer methods, the tank environment should also be documented as completely as possible. A detailed site diagram should be prepared which identifies the positions of the tanks, piping, and other features which are present at the site. The type of backfill and soil at the site should be verified, at the minimum, to be porous enough to allow migration of vapors from the leak to the sensors. The evaluation should not be run under backfill conditions outside the range suggested by the vendor.

Both normal and "unacceptable" test conditions for each method should be described in the operating manual for the method and should provide a reference against which the existing test conditions can be compared. The evaluation should not be done under conditions outside the vendor's recommended operating conditions.

Pertaining to the tank and the product, the following items should be recorded if applicable:

- type of product in tank
- type of tracer(s) (liquid or gas)
- tank volume
- tank dimensions and type
- amount of water in tank (before and after each test)
- if applicable, temperature of product in tank before filling
- if applicable, temperature of product added each time the tank is filled
- if applicable, temperature of product in tank immediately after filling
- if applicable, temperature of product in tank at start of test

6.2 INDUCED LEAK RATES AND TEMPERATURE DIFFERENTIALS

Following a trial run in the tight tank, a minimum of 42 tests must be performed according to an experimental design illustrated in Table 1. (As discussed in Section 7, a larger number of tests could be used.) For illustrative purposes, this table presumes that temperature and tank deflection effects could interfere with the method.

Table 1. LEAK RATE AND TEMPERATURE DIFFERENTIAL TEST SCHEDULE (Example)

Test No.	Set No.	Nominal Leak Rate (gal/h)	Nominal Temperature Differential *1 (degree,F)
Trial run		0	0
Empty/Fill cycle *2			
1	1	LR2	T3
2	1	LR1	T3
Empty/Fill cycle			
3	2	LR1	T2
4	2	LR1	T2
Empty/Fill cycle			
5	3	LR1	T1
6	3	LR3	T1
Empty/Fill cycle			
7	4	LR3	T3
8	4	LR1	T3
Empty/Fill cycle			
9	5	LR4	T1
10	5	LR1	T1
Empty/Fill cycle			
11	6	LR2	T2
12	6	LR3	T2
Empty/Fill cycle			
13	7	LR4	T1
14	7	LR1	T1
Empty/Fill cycle			
15	8	LR3	T3
16	8	LR1	T3
Empty/Fill cycle			
17	9	LR4	T3
18	9	LR1	T3
Empty/Fill cycle			
19	10	LR1	T2
20	10	LR3	T2
Empty/Fill cycle			
21	11	LR3	T1
22	11	LR1	T1

Note 1: The temperature differential is calculated as the temperature of the product added minus the temperature of the product in the tank.

Note 2: Empty/Fill cycles and temperature differentials may not be required.

Table 1. LEAK RATE AND TEMPERATURE DIFFERENTIAL TEST SCHEDULE (Example) (Continued)

Test No.	Set No.	Nominal Leak Rate (gal/h)	Nominal Temperature Differential *1 (degree F)
Empty/Fill cycle *2			
23	12	LR1	T3
24	12	LR2	T3
Empty/Fill cycle			
25	13	LR2	T2
26	13	LR4	T2
Empty/Fill cycle			
27	14	LR3	T3
28	14	LR1	T3
Empty/Fill cycle			
29	15	LR1	T1
30	15	LR2	T1
Empty/Fill cycle			
31	16	LR1	T2
32	16	LR1	T2
Empty/Fill cycle			
33	17	LR1	T3
34	17	LR4	T3
Empty/Fill cycle			
35	18	LR1	T2
36	18	LR4	T2
Empty/Fill cycle			
37	19	LR2	T1
38	19	LR1	T1
Empty/Fill cycle			
39	20	LR1	T2
40	20	LR2	T2
Empty/Fill cycle			
41	21	LR1	T1
42	21	LR4	T1

Note 1: The temperature differential is calculated as the temperature of the product added minus the temperature of the product in the tank.

Note 2: Empty/Fill cycles and temperature differentials may not be required.

In Table 1, LR_i denote the nominal leak rates and T_i denote the temperature differential conditions to be used in the testing. These 42 tests evaluate the method under a variety of conditions.

The 42 tests are arranged in 21 sets of two tests each. Table 1 shows a possible ordering of the 21 sets. In practice, the evaluating organization should randomly rearrange the order of the sets so that the leak rates are blind to the vendor.

Leak Rates

Of the 42 tests, half will be performed under tight-tank conditions, that is, at a leak rate of 0.0 gallon per hour. The remaining 21 tests will be performed under induced leak conditions with leak rates not exceeding 0.10 gallon per hour. Typically, all of these induced leak rates would be the same. Alternatively, different non-zero leak rates could be used and the results analyzed with a logistic model, as described in Section 7.4.2. The test schedule in Table 1 is an example of 21 tests at a 0.0 gallon per hour leak rate (LR_1) and 3 groups of 7 tests at non-zero leak rates of LR_2, LR_3, and LR_4, which may all be equal.

The most direct evaluation of a nonvolumetric method uses only the zero and 0.10 gallon per hour leak rates. This, assuming that the test results had at most one error at each leak rate, would provide the needed performance evaluation. However, a vendor may want to claim that his method exceeds the EPA performance standards and establish that the probability of detecting a smaller leak (e.g., 0.01 rather than 0.10 gallon per hour) is at least 95%. In that case, two approaches are possible. One is to use the smaller leak rate as the induced leak rate. Again, this is straightforward. However, if the nominal leak rate selected is close to or less than the leak rate that the method can actually detect with 95% reliability, the testing may result in too many detection errors at that reduced leak rate. In order to demonstrate that the method meets the performance standards, the 21 induced leak rate tests would have to be run again using a nominal leak rate larger than the example of 0.01 gallon per hour (e.g., 0.05 gallon per hour), with additional costs for the evaluation.

Another approach is to induce three non-zero leak rates and estimate the probability of detection as a function of the leak rate. In this case, the method would demonstrate that it meets the EPA performance standards, provided that the probability of detection at a zero leak rate (a false alarm) is less than 5%, and the detectable leak rate that could be claimed by the method is the leak rate at which the function first exceeds 95%. If this option is chosen, a single test series of 42 tests could demonstrate that the method meets the EPA performance standards at the smaller leak rate determined by the evaluation. In order for this approach to work, the probability of detecting a leak must increase steadily with the leak rate. In addition, the non-zero leak rates must be selected so that the observed results (proportions of tests where a leak is detected) also increase with the induced leak rate. There must be very few detections (zero or one) at zero, some missed detections at the smaller leak rates, and very few at the larger leak rates.

Temperature Differentials (if applicable)

If temperature differential is important for the test method, three nominal temperature differentials between the temperature of the product to be added and the temperature of the product in the tank during each fill cycle should be used. These three temperature differentials are -5°, 0°, and +5°F (-2.8°, 0°, and +2.8°C). The temperature differential of 5°F is a minimum. Larger differences may be used. If temperature differences are used, the actual differences are to be calculated and reported.

Randomization

A total of 42 tests consisting of combinations of the four leak rates (LR_1 = 0.0 gallon per hour, LR_2, LR_3, and LR_4) and the three temperature differentials (T_1, T_2, and T_3) will be performed. LR_2, LR_3, and LR_4 may all be the same, depending on the analysis method to be used. The 42 tests have been arranged in pairs (sets), each pair consisting of two tests performed at the same temperature differential. However, the leak rates within a pair have been randomly assigned to the first or second position in the testing order. The test schedule is outlined in Table 1.

A randomization of the test schedule is required to ensure that the testing is done blind to the vendor. The randomization of the tests is achieved by the evaluating organization by randomly assigning three nominal leak rates below 0.10 gallon per hour to LR_2, LR_3, and LR_4 and by randomly assigning the nominal temperature differentials of 0°, -5°, and +5°F to T_1, T_2, and T_3, following the sequence of 42 tests as shown in Table 1. In addition, the evaluating organization should randomly assign the set numbers (1 through 21) to the 21 pairs of tests. The results of the randomized sequence should be kept blind to the vendor. That is, the vendor should not know which induced leak rate is used or which temperature condition is present in advance. The vendor should test for the induced leak rate based on his instrumentation and standard operating procedure without knowledge of the induced conditions. Randomization should be done separately for each method evaluated.

In summary, each test set consists of two tests performed using two induced leak rates and one induced temperature differential (temperature of product to be added - temperature of product in the tank). Each set indicates the sequence in which the induced rates are used to remove the product volumes (in gallons per hour) from the tank at a given product temperature differential. In some cases, e.g., when a partial vacuum is applied to the tank, the simulated leak will not actually remove product from the tank. In this case, the indicated rates are those at which product would escape or be removed from the tank if the induced condition were present under normal tank operating conditions.

Notational Conventions

The nominal leak rates to be induced are denoted by LR_1 = 0.0 gallon per hour, LR_2, LR_3, and LR_4. It is clear that the nominal leak rates selected by the evaluating organization cannot be achieved exactly in the field. Rather, these numbers are targets that should be established by a calibration process. The maximum must be no more than 10% greater than the nominal 0.10 gallon per hour.

The leak rates actually induced for each of the 42 tests will be calibrated for each test series. They will be denoted by $S_1, S_2, \ldots, S_{42}$. The results of each test will be denoted by $L_1, \ldots, L_{42}$, with each L_i being either "tight" or "leaking." The L_i may be coded numerically, e.g., L_i = "0" for tight and "1" for leaking, for convenience.

The subscripts 1,...,42 correspond to the order in which the tests were performed (see Table 1). That is, for example, S_5 and L_5 correspond to the test results from the fifth test in the test sequence.

6.3 TESTING SCHEDULE

The first test to be done is a trial run. This test should be done with a tight tank in a stable condition and this should be known to the vendor. The results of the trial run will be reported along with the other data, but are not explicitly used in the calculations estimating the method's performance.

There are two purposes to this trial run. One is to allow the vendor to check out the tank testing equipment before starting the evaluation. As part of this check, any faulty equipment should be identified and repaired. A second part is to ensure that there are no problems with the tank or the test equipment. Such practical field problems as loose risers, leaky valves, leaks in plumber's plugs, etc., should be identified and corrected with this trial run. The results also provide additional verification that the tank is tight and so provide a baseline for the induced leak rates to be run in the later part of the evaluation.

The testing will be performed using a randomized arrangement of nominal leak rates and temperature differentials as illustrated in Table 1 above, unless the evaluating organization determines that the filling and/or temperature changes are irrelevant for the particular nonvolumetric method. The time lapse between the two tests in each set should be kept as short as practical. It should not exceed 30 min, and preferably should be held to 15 min or less. Twenty-one sets of two tests each will be carried out. After each set of two tests, the test procedure starts anew with emptying the tank to half full, refilling, stabilizing, etc., as necessary. The details of the testing schedule are presented next, in accordance with the example ordering shown in Table 1.

Step 1: Randomly assign nominal leak rates not to exceed 0.10 gallon per hour to LR_2, LR_3, and LR_4. Note that LR_1 is identified with the zero leak or tight tank condition as 21 trials are run in this condition. Also, randomly assign the temperature differentials of 0°, -5°, and +5°F to T_1, T_2, and T_3. This will be done by the organization performing the evaluation and needs to be kept blind to the crew performing the testing.

Step 2: Follow the vendor's instructions to install the leak simulation equipment in the tank if this has not already been done, making sure that the leak simulation equipment will not interfere with the test equipment.

Step 3: **Trial run.** Following the test method's standard operating procedure, fill the tank to the recommended level, and allow for the stabilization period called for by the method or longer. Any product added should be at the same temperature as that of the in-tank product. Conduct a test on the tight tank to check out the system (tank, plumbing, etc.) and/or the method. Perform any necessary repairs or modifications identified by the trial run.

Step 4: Empty the tank to half full. Fill with product at the recommended temperature. The temperature differential will be T_3 (Table 1, Test No. 1). Record the date and time at the completion of the fill. Allow for the recommended stabilization period, but not longer. Induce the appropriate leak condition.

Step 5: Continue with the method's standard operating procedure and conduct a test on the tank, using the method's recommended test duration. Record the date and time of starting the test. This test will be performed under the first nominal leak rate of the first set in Table 1. This nominal leak rate to be induced is LR_2.

When the first test is complete, determine and record the calibrated induced leak rate, S_1, and the method's reported leak condition, L_1. If possible, also record the data used to determine the leak condition and the method of calculation. Save all data sheets, computer printouts, and calculations. Record the dates and times at which the test began and ended. Also record the length of the stabilization period. The Individual Test Log form in Appendix B is provided for the purpose of reporting these data and the environmental conditions for each test.

Record the temperature of the product in the test tank and that of the product added to fill the test tank (if done; if not, document why not on the log). After the product has been added to fill the test tank, record the average temperature in the test tank. Measuring the temperature of the product in the tank is not a trivial task. One suggested way to measure the temperature of the product in the tank is to use a probe with five temperature sensors spaced to cover the diameter of the tank. The probe is inserted in the tank (or installed permanently), and the temperature readings of those sensors in the liquid are used to obtain an average temperature of the product. The temperature sensors can be spaced to represent equal volumes or the temperatures can be weighted with the volume each represents to obtain an average temperature for the tank.

Step 6: Change the nominal leak rate to the second in the first set, that is LR_1 (see Table 1). **Repeat Step 5.** Note that there will be an additional period (the time taken by the first test and the set-up time for the second test) during which the tank may have stabilized. When the second test of the first set is complete, again record all results (times and dates, induced leak rate and test result, temperatures, calculations, etc.).

Step 7: **Repeat Step 4.** The temperature differential will be changed to T_2.

Step 8: Change the nominal leak rate to the first in the second set. In this example, the rate is unchanged at LR_1. **Repeat Step 5.** Record all results.

Step 9: Change the nominal leak rate to the second in the second set if it is different. In this example the second leak rate is LR_1. **Repeat Step 6.** Record all results.

Step 10: **Repeat Step 4.** The temperature differential will be changed to the following one in Table 1. In this case, it will be changed to T_1.

Step 11: **Repeat Steps 5 through 9,** using each of the two nominal leak rates of the third set, in the order given in Table 1.

Steps 4 through 9, which correspond to two empty/fill cycles and two sets of two tests, will be repeated until all 42 tests are performed.

Normal and "unacceptable" test conditions for each method should be described in the owner operating manual for each method and should provide a reference against which the existing test conditions are compared. The evaluation should not be done under conditions outside the vendor's recommended operating conditions.

6.3.1 Application of the Protocol to Acoustical Methods

One class of commercially available nonvolumetric test methods is based on acoustical principles. This section describes the application of the protocol to this type of method. A basic description of the method is needed to understand the application of the protocol.

Acoustical methods use sensitive hydrophones to detect an acoustical signal from the tank. This signal is recorded and is analyzed to identify a specific characteristic associated with a leak. One such method places the tank under a partial vacuum and investigates the acoustical signal for a characteristic "bubble" signature induced when air bubbles are drawn from outside the tank (in an unobstructed backfill zone) into a liquid through a hole in the tank. Leaks in the ullage are identified by a particular frequency or "whistle" of air ingressing into the ullage space. Another approach analyzes the acoustical signal for a characteristic sound of fluid flowing out of an orifice in the tank.

While these methods have been called "acoustical," they typically have additional modes of detecting leaks that are used in conditions of a high ground-water level. Generally they rely on identification of water ingress to detect leaks in the presence of a high ground-water level. The evaluation must test all modes of leak detection used by the method to "detect leaks from any portion of the tank that normally contains product." Section 6.5 contains a protocol to evaluate a water sensor used to detect inflow of water during a test period.

Acoustical methods can be used with a fairly wide range of product ~~levels~~ in the tank. The deformation caused by filling the tank would not affect these methods, nor would the temperature of the product in the tank. Consequently, the sequence of temperature and filling conditions does not need to be considered with these tests. The tank should be filled to a level in the range specified by the method.

To induce a leak for the acoustical methods, it is necessary to use a device that will create the same signal that a real leak would create. One way to do this is to use an orifice-type leak simulator. This consists of a pipe inserted into the tank through one of the tank openings. The pipe is sealed to the tank. The bottom of the pipe is fitted with a cap that contains a calibrated orifice to allow product to leak into the pipe at the desired leak rate under a standard head. This simulator will work for either type of acoustical signal. Flow of liquid through the orifice would produce the signal typical of liquid flow. If the tank is under partial vacuum, air will be drawn into the tank through the orifice below the liquid level and will produce bubbles. A means of closing the orifice is needed so that a zero leak rate can be induced and kept blind to the vendor.

Since neither temperature differential nor tank deformation should affect the acoustical methods, the approach discussed earlier in this subsection is simplified as follows. The steps refer to Table 1, with the understanding that there are no differences among T_1, T_2, T_3, and the partial emptying and refilling is not necessary.

Step 1: Decide whether one or three non-zero leak rates will be used. (The use of three may allow one to fit a model relating probability of detection to leak rate, but if this is not important to the vendor, it is sufficient to use a single non-zero leak rate (less than or equal to 0.10 gallon per hour), which may be the preferred approach.)

Step 2: Decide what leak rates will be used. If only a single non-zero leak rate is used, it can be selected between zero and 0.10 gallon per hour. If the vendor wants to establish a smaller detectable leak rate, a value of less than 0.10 gallon per hour may be used. (The risk of doing this is that if the system does not pass, more testing with larger leak rates below 0.10 gallon per hour may be needed.)

Step 3: If only two leak rates (0 and one other) are used, randomly assign one of them to LR_1 and the other to all cases where LR_2, LR_3, or LR_4 are listed. If four leak rates are to be used, assign LR_1 to zero and randomly assign the other three to LR_2, LR_3, and LR_4.

Step 4: Randomly rearrange the order of the 21 pairs of tests listed in Table 1. (This allows for additional randomization and provides better control on keeping the induced leak rates blind to the vendor.)

Step 5: Have the vendor install the test equipment in the tank.

Step 6: **Trial run.** Following the test method's standard operating procedure, fill the tank to the recommended level. Have the vendor conduct a test with a known zero leak rate and verify that the equipment has been installed and is functioning correctly. This also provides confirmation that the tank is still tight and is compatible with the test method.

Step 7: Induce the leak rate called for in the randomization developed above. Have the vendor test the tank with this induced leak rate and report the results. Record the calibrated induced leak rate and the vendor's results (tight or leaking). Record the environmental conditions data and other ancillary data on the test logs (see Appendix B).

Step 8: When the first test is completed, change the leak rate to establish the second leak rate called for in the randomized series (Table 1). When this induced rate has been established, have the vendor test the tank. Record the environmental conditions data. When the vendor has completed the test, record his reported result and the induced leak rate.

Step 9: Repeat step 8 until all 42 tests have been completed.

As will be described in Section 7, the system can produce no more than one false alarm and still pass. Thus, if a second false alarm occurs in the test series, the system will not pass, and testing could be terminated. Similarly, if only one non-zero leak rate is used, and if a second mistake is made with that non-zero leak rate, the system will not pass. At the point where the evaluating organization determines that the system will not pass, it might be desirable to conclude testing. The series could be completed to provide added information to the vendor. If a leak rate of less than 0.10 gallon per hour was used, starting the test series again with a leak rate closer to 0.10 gallon per hour might be done since the method might pass at that rate but not at the smaller leak rate. If no errors have occurred when 20 tight tank or 20 induced leak tests have been done, the system will pass. Since only one more test is needed, it probably would not effect much savings to stop at this point.

6.3.2 Application of the Protocol to Tracer Methods

There are many variables present in external monitoring that are difficult to predict or control. These include the nature of the backfill material, moisture content of the soil, size of the excavation, type of soil surrounding the excavation, the ground-water level, position of a leak relative to the sampling locations, and whether the method is aspirated or passive. In general, some minimum threshold concentration of tracer must be reached before a signal is generated. The lower the threshold, the more sensitive the method, but the more susceptible it will be to false alarms.

For test methods that involve the loss of product from the tank, the induced leak rates should be designed to introduce the amount of tracer material into the soil that would be released by leak rates of the specified size over the test period. Methods that add liquid tracer to the product specify a concentration of the tracer in the product. Using this concentration (e.g., 10 ppm), a leak rate (e.g., 0.10 gallon per hour) and a test and waiting time after introducing the tracer into the tank (e.g., 24 hours), one can calculate the amount of tracer that would be released. This is the amount that should be released during the leak simulation. A suggested way to accomplish this is to make up samples of a carrier that can be introduced into the environment, say vegetable oil, with tracer added in the appropriate concentrations. These samples can be used to spike the ground at small rates, giving the same amount of tracer that would be released by the specified leak rates.

If the method uses gas tracers, they can be introduced into the ground to simulate leaks by using a flowmeter to allow the gas to flow at the rate that would occur under the testing conditions, e.g., in a tank at 2 PSI and through a small orifice, representing a hole that would leak liquid product at the designated leak rates (less than 0.10 gallon per hour).

Note that once a tracer, gas or liquid, has been introduced into the soil in a test, the tracer must be eliminated before the next test. Forced air may be used to disperse the tracer to levels that will not be detected and interfere with the method; the next test may be conducted with a different tracer; or a different site may be used.

The following steps assume that multiple tracers are available, one of which is used in the tank to investigate the false alarm possibilities, and others that are used in leak simulations.

Neither the temperature conditioning nor tank stabilization is an issue with tracer methods. Consequently, it is not necessary to change fuel temperatures and fill and empty the tank frequently as part of the evaluation. At least 21 tests of the tank in the no-leak condition are required, as are at least 21 tests using the induced leaks.

Step 1: Decide whether a single non-zero leak or three non-zero leak rates will be used and select these leak rates.

Step 2: Identify the zero leak rate with LR_1 in Table 1. Randomly assign the other leak rate(s) to LR_2, LR_3, and LR_4.

Step 3: Randomly rearrange the order of the 21 pairs of tests in Table 1 that result from the assignment of the leak rates.

Step 4: Determine the rate of introducing tracer (if a gas) or liquid carrier and tracer (if a liquid) into the backfill to simulate the selected leak rates. If a liquid tracer is used, prepare samples with the carrier and tracer in the needed concentrations, label these with the randomized test sequence, and provide them to the test crew. The crew should not know whether or in what concentration the tracer is in the leak simulation samples.

Step 5: Prepare the tank. If a liquid tracer is used, have the vendor introduce it at the desired concentration into the test tank and fill the tank to the desired level following normal operating procedures for the method. If a gas tracer is used, empty the tank and have the vendor introduce the gas to the tank. The tank thus prepared will serve to provide the data on the zero leak rates.

Step 6: Have the vendor locate the sampling ports. Also locate a spiking port for leak simulation as far from the sampling ports and as close to the tank as possible. Be careful not to damage the tank in installing the ports in the backfill.

Step 7: Conduct the trial run. For tracer methods, the trial run will be of a different nature than for other methods. The trial run for a tracer usually consists of verifying that the site conditions allow the use of a tracer method. A compound is introduced at the spiking port. The test locations are sampled to determine whether the compound is detected at the sampling locations. The trial run accomplishes two purposes. First, it verifies that the soil or backfill conditions are such that the tracer can migrate from the tank to the sensors. Second, it determines the time needed for the migration and so establishes a test time.

Step 8: Have the vendor conduct a test of the tank (zero leak rate).

Step 9: Begin testing using the first non-zero leak rate. Have the vendor conduct a test. Note: If two different tracers are used, it may be possible for the vendor to conduct the test on the tank (zero leak rate) and the induced leak test at the same time.

Step 10: When the test in step 8 and/or 9 is completed, record the induced leak rate, the vendor's determination (tight or leaking), and the environmental conditions data on the test log (see Appendix B).

Step 11: Ensure that the test site can be used for a second leak test (by removing the current tracer or using a different one). Start the next induced leak rate as in steps 8 and 9 and have the vendor conduct another test. Record all results.

Step 12: Repeat step 11 until the test series is completed.

It should be possible for the vendor to conduct tests on the tank containing the tracer repeatedly for the zero leak rate tests. In conducting the repeated tests on the tight tank to estimate the false alarm rate, the steps of adding tracer to the product and mixing the tracer in the product should be repeated. The process of adding and mixing tracer is a likely cause of false alarms as it could lead to inadvertent release of tracer into the environment that could be mistaken for a leak. It should be possible to simulate the addition and mixing of the tracer by using tracer-containing product and handling it in the same manner as the tracer solution.

Assuming that at least two tracers are available, the tight tank tests and the simulated leak tests can be run simultaneously. For each test, the carrier sample is introduced in the spiking port. The containers of carrier are made up in advance and coded. Half of them contain tracer and half do not. Each test would consist of introducing one tracer (say type A) into the tank and another sample (either a blank or containing tracer type B) into the spiking port. The testing company samples the soil gas and reports on the presence of any detected tracer. A finding of tracer A would be a false alarm. A finding of tracer B (when it was spiked) would be a correct detection. If additional distinct tracer compounds are used, this process could continue spiking tracer C, etc. A finding of both tracer B (from a previous spike) and tracer C from the current spike would be a correct detection.

As will be described in Section 7, the system can record only one false alarm and still pass. Thus, if a second false alarm occurs in the test series, the system will not pass, and the evaluating organization may recommend to the vendor that testing might be terminated. Similarly, if only one non-zero leak rate is used, and if a second mistake is made with that non-zero leak rate, the system will not pass. At the point where the evaluating organization determines that the system will not pass, it might be desirable to conclude testing. If a leak rate of less than 0.10 gallon per hour was used, starting the test series again with a leak rate closer to 0.10 gallon per hour might be done since the method might pass at that rate but not at the smaller leak rate.

6.4 TESTING PROBLEMS AND SOLUTIONS

Inevitably, some test runs will be inconclusive due to broken equipment, spilling of product used to measure the induced leak rate, or other events that have interrupted the testing procedure. It is assumed that, in practice, the field personnel would be able to judge whether a test result is valid. Should a run be judged invalid during testing, then the following rules should apply.

Rule No. 1 The total number of tests must be at least 42. That is, if a test is invalid, it needs to be rerun. Report the test results as invalid together with the reason and repeat the test.

Rule No. 2 If equipment fails during the first run (first test of a set of two) and if the time needed for fixing the problem(s) is less than 4 hours, then repeat that run. Otherwise, repeat the empty/fill cycle, the stabilization period, etc. Record all time periods.

Note: The average stabilization time or average time after introducing the tracer will be reported on the Results of U.S. EPA Standard Evaluation form in Appendix B. If the delay would increase this time noticeably, then the test sequence should be redone.

Rule No. 3 If equipment fails during the second run (after the first run in a set has been completed successfully), and if the time needed for fixing the problem(s) is less than 4 hours, then repeat the second run. Otherwise, repeat the whole sequence of empty/fill cycle, stabilization, and test at the given conditions.

Rule numbers 2 and 3 are only applicable if the testing schedule requires temperature conditioning and tank deformation effects. Otherwise, the time between tests is not an important limitation.

Note that an acceptable alternative to conducting the tests in pairs is to set up the tank conditions (as required) for each test. Thus, while the protocol allows for the tests to be run in pairs for economy, they may all be run individually.

6.5 METHOD EVALUATION PROTOCOL FOR WATER DETECTION

Some methods rely on detection of water incursion to identify leaks in the presence of a high ground-water level. These often use a water sensor installed at the bottom of the tank. A standpipe device to test the function of the water sensor consists of a cylinder with an accurately known (to ± 0.001 inch) inside diameter attached to the bottom of a pipe of 4- to 6-inch diameter pipe. The probe is mounted so that the sensor is in the same relation to the bottom of the cylinder as to the bottom of a tank when installed in the field. Enough product is put into the cylinder and pipe so that the product level sensor is high enough so as not to interfere with the water sensor. A measured amount of water is then added to the cylinder until the water sensor detects it, at which time the water level is calculated and recorded. Additional measured amounts of water are added to produce calculated level changes. The amount of water added, the calculated level change, and the level change measured by the method are recorded. This is done over the range of the water sensor or 4 inches, whichever is less. When testing is complete, the product and water are removed, separated, and the process is repeated. The testing procedure is given in detail next.

Step 1: Install the probe temporarily in a test standpipe. The bottom section of about 1 foot should have an accurately known (to ±0.001 inch) inside diameter. The diameter must be large enough to accommodate the probe and must be known accurately so that the volume of water added can be used to calculate the water level.

Step 2: Fill the bottom section of the standpipe with the product (typically this will require a gallon or less). Enough product needs to be added so that the product level sensor is high enough not to interfere with the water sensor.

Step 3: Add water to the cylinder with a pipette until the sensor detects the presence of the water. Record the volume of water added and the sensor reading at each increment. The sensor reading will be zero until the first sensor response. At that point, total the water increments and calculate the corresponding level, X_1, of water detected. Record all data on page 1 of the Reporting Form for Water Sensor Evaluation Data in Appendix B.

Step 4: Add water to the cylinder with a pipette in increments to produce a height increment, h, of approximately 1/20th inch. At each increment, record the volume of water added and the water height (denoted by $W_{i,j}$, in Table 2 of Section 7.2) measured by the sensor. Use pages 2 to 4 as necessary of the Reporting Form for Water Sensor Evaluation Data in Appendix B. Repeat the incremental addition of water 60 times until a total height of about 3 inches (or the range limit of the sensor, if less) has been reached.

Step 5: Empty the product and water from the standpipe, refill with product (the same product can be used after separating the water) and repeat Steps 2 through 4 20 times to obtain 20 replications.

Record all data using the Reporting Form for Water Sensor Evaluation Data in Appendix B. The 20 minimum detectable water levels are denoted by X_j, $j=1,\ldots,20$. The sensor reading at the i^{th} increment of the j^{th} test is denoted by $W_{i,j}$ as described in Section 7.2 and Table 2.

SECTION 7

CALCULATIONS

From the results obtained after all testing is completed, a series of calculations will be performed to evaluate the method's performance. If the method has more than one mode of leak detection, then the performance of the method must be evaluated and the results reported for each testing mode separately. If the performance is different for different modes, this may limit the conditions under which the method can be used and these should be reported under the limitations section of the results form.

The evaluation of the nonvolumetric test method is presented first. A separate section (7.2) presents the calculations to estimate the minimum water level and the minimum water level change that the water sensor can detect. Section 7.2 is only needed if the method measures or detects water incursion as one mode of its leak detection.

The performance of the nonvolumetric test method is judged on the basis of the percentage of false alarms and the percentage of correctly identified leaks. The performance standards specify that the false alarm rate must be no more than 5% and that the probability of detecting a leak rate of 0.10 gallon per hour must be at least 95%. The test procedure includes 21 tests of the tank in the no-leak condition and 21 tests of the tank with leaks induced at rates of 0.10 gallon per hour or less. These data are used to estimate the probability of false alarm and probability of detection directly.

7.1 ESTIMATION OF THE METHOD'S PERFORMANCE PARAMETERS

After all tests are performed according to the schedule outlined in Section 6, a total of at least 42 test results will be available. Of these, 21 will have been obtained under tight tank conditions, and 21 under induced leak conditions. The probability of false alarm, P(FA), and the probability of detection, P(D), are calculated next.

7.1.1 False Alarm Rate, P(FA)

The results obtained from the tests performed under tight tank conditions will be used to calculate P(FA). Let N_1 denote the number of these tests, normally 21. (Note: This number must be at least 21, but could be larger if more tests are called for in the experimental plan set up at the beginning of the testing.) Let TL_1 denote the number of cases where the method indicated a leak. If the test results, L_i, are coded as zero when no leak is indicated and 1 when a leak is indicated, then

$$TL_1 = \sum_{i=1}^{N_1} L_i$$

where the sum is taken over the N_1 tests at zero leak rate. The P(FA) is estimated by the ratio

$$P(FA) = TL_1/N_1$$

In order for the system to meet the performance standards, the estimated P(FA) must be less than or equal to 5%. Thus, in order for the system to meet the performance standards, TL_1 must be no more than 1 if the standard 21 tests are performed.

If the method did not identify the tank to be leaking when it was tight, that is, $TL_1 = 0$, then the proportion of false alarms becomes 0%. However, this does not mean that the method is perfect. The observed P(FA) of 0% is an estimate of the false alarm rate based on the evaluation test results and the given test conditions.

One can calculate an upper confidence limit for P(FA) in the case of no mistakes. Let N_1 be the number of tests performed under the tight tank condition. Choose a confidence coefficient, $(1 - \alpha)$, say 95% or 90%. Then the upper confidence limit, UL, for P(FA) is calculated as:

$$\text{UL for } P(FA) = 1 - \alpha^{1/N_1}$$

In the case of 0 false alarms out of 21 tests, the upper limit to P(FA) becomes 0.133 or 13.3% with a 95% confidence coefficient. That is, P(FA) is estimated at 0%, and with a confidence of 95%, P(FA) is less than or equal to 13.3%. In general the confidence interval for P(FA) can be calculated from the binomial distribution with N_1 trials. The 95% confidence interval must be calculated and reported on the results form in Appendix B (see page 48).

7.1.2 Probability of Detecting a Leak, P(D)

The probability of detection, P(D), is calculated for a specific size of leak. The size of leak that can be detected with this probability is also to be reported. Normally this will be 0.10 gallon per hour, as required by the performance standards. The exception to this would occur if a method is tested using induced leak rates smaller than 0.10 gallon per hour, for example, 0.05 gallon per hour. Report the probability of detection, P(D), together with the maximum leak rate used in the evaluation testing. The leak rate corresponding to the P(D) will be 0.10 gallon per hour or less.

The results obtained from the tests performed under induced leak conditions (leak rates less than or equal to 0.10 gallon per hour) will be used to calculate P(D). Let N_2 be the number of such tests. Typically, N_2 will also be 21, but could be larger if the evaluation was initially set up to include more tests. Let TL_2 be the number of cases where the method indicated a leak. As before, the test results, L_i, are coded as zero when the tank is declared to be tight and 1 when the tank is declared to be leaking. Thus, TL_2 is calculated as

$$TL_2 = \sum_{i=1}^{N_2} L_i$$

where the sum is taken over the N_2 tests with induced leaks. The P(D) is then estimated by the ratio

$$P(D) = TL_2/N_2$$

The estimated P(D) must be at least 95% for the system to meet the performance standards. Thus, TL_2 must be either 20 or 21 (out of 21 tests) for the estimated probability of detection to be at least 95%.

If the method identified the tank to be leaking in all tests where a leak was simulated, then the proportion detected becomes 100%. However, this does not mean that the method is perfect. The P(D) of 100% is an estimate of the probability of detection, based on the evaluation test results and the given test conditions.

One can calculate a lower confidence limit for P(D) in the case of no mistakes. Let N_2 be the number of tests performed under the induced leak conditions. Choose a confidence coefficient, $(1 - \alpha)$, say 95% or 90%. Then the lower confidence limit, LL, for P(D) is calculated as:

$$\text{LL for } P(D) = \alpha^{1/N_2}.$$

In the case of correct identification of 21 tests performed under leak conditions, the lower limit to P(D) becomes 0.867 or 86.7% with a 95% confidence coefficient. That is, P(D) is estimated at 100%, and with a confidence of 95%, P(D) is greater than or equal to 86.7%. The 95% confidence interval for P(D) must be calculated based on the binomial distribution with N_2 trials and reported on the results form in Appendix B (see page 48).

7.2 WATER DETECTION MODE

This section is only applicable if the method being evaluated uses detection of water incursion as a leak detection mode.

Two parameters will be estimated for the water detection sensor: the minimum detectable water level or threshold that the sensor can determine, and the smallest change in water level that the device can record. These results will also be reported on the Results of U.S. EPA Standard Evaluation form in Appendix B. These parameter estimates will then be used to calculate the minimum time needed to detect water incursion at 0.10 gallon per hour for various tank sizes.

7.2.1 Minimum Detectable Water Level

The data obtained consist of 20 replications of a determination of the minimum detectable water level (see test schedule, Section 6.5). These data, denoted by $X_j, j=1,...20$, are used to estimate the minimum water level, or threshold, that can be detected reliably.

Step 1: Calculate the mean, $\overline{X}$, of the 20 observations:

$$\overline{X} = \sum_{j=1}^{20} X_j/20$$

Step 2: Calculate the standard deviation, SD, of the 20 observations:

$$SD = \left[\frac{\sum_{j=1}^{20} (X_j - \overline{X})^2}{20-1} \right]^{1/2}$$

Step 3: From a table of tolerance coefficients, K, for one-sided normal tolerance intervals with a 95% probability level and a 95% coverage, obtain K for a sample size of 20. This coefficient is K = 2.396. (Reference: Lieberman, Gerald F. 1958. "Tables for One-Sided Statistical Tolerance Limits." *Industrial Quality Control*. Vol. XIV, No. 10.)

Step 4: Calculate the upper tolerance limit, TL, for 95% coverage with tolerance coefficient 95%:

$$TL = \bar{X} + K\ SD,$$

or

$$TL = \bar{X} + 2.396\ SD$$

TL estimates the minimum level of water that the sensor can detect. That is, with 95% confidence, the method should detect water at least 95% of the time when the water depth in the tank reaches TL.

7.2.2 Minimum Water Level Change

The following statistical procedure provides a means of estimating the minimum water level change that the water sensor can detect, based on the schedule outlined in Section 6.5.

Denote by $W_{i,j}$ the sensor reading (in inches) at the jth replicate ($j=1,...,20$) and the ith increment ($i=1,...,n_j$, with n_j being 60 in each replicate). Note that the number of steps in each replicate need not be the same, so the sample sizes are denoted by n_j. Denote by X_j the water level detected for the first time by the sensor at the jth replicate.

Denote by h the level change induced at each increment. The level change, h, should be chosen to be consistent with the system's claimed resolution. That is, the increments should be about half (or less) of the method's claimed resolution.

Step 1: Calculate the differences between consecutive sensor readings. The first increment will be $W_{1,1}-X_1$ for the first replicate ($j=1$); more generally, $W_{1,j}-X_j$, for the jth replicate. The second increment will be $W_{2,1}-W_{1,1}$ for the first replicate; more generally, $W_{2,j}-W_{1,j}$ for the jth replicate, etc.

Step 2: Calculate the difference, at each incremental step, between h, the level change induced during testing, and the difference obtained in Step 1. Denote these differences by $d_{i,j}$, where i and j represent increment and replicate numbers, respectively. Table 2 below summarizes the notations.

Table 2. NOTATION SUMMARY FOR WATER SENSOR READINGS AT THE jth REPLICATE

Increment No.	Calculated level change (inch) A	Sensor reading (inch) B	Measured sensor increment (inch) C	Increment difference calculated-meas. (inch) C-A
1	+ h	$W_{1,j}$	$W_{1,j}-X_j$*	$d_{1,j}$
2	+ h	$W_{2,j}$	$W_{2,j}-W_{1,j}$	$d_{2,j}$
3	+ h	$W_{3,j}$	$W_{3,j}-W_{2,j}$	$d_{3,j}$
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
n_j	+ h	$W_{n_j,j}$	$W_{n_j,j}-W_{n_j-1,j}$	$d_{n_j,j}$

* X_j is the water level (inches) detected for the first time by the sensor during the jth replication of the test.

Note that using the first sensor reading, X_j, may vary from replicate to replicate, so that the number of differences $d_{i,j}$ will also vary. Let n_j be the number of increments necessary during replicate j.

Step 3: Calculate the average, D_j, of the differences $d_{i,j}$, $i=1,\ldots,n_j$, separately for each replicate j, $j=1,\ldots,20$.

$$D_j = \sum_{i=1}^{n_j} d_{i,j}/n_j$$

Step 4: Calculate the variance of the differences $d_{i,j}$, $i=1,\ldots,n_j$ separately for each replicate j, $j=1,\ldots,20$.

$$Var_j = \sum_{i=1}^{n_j} (d_{i,j} - D_j)^2/(n_j-1)$$

Step 5: Calculate the pooled variance, Var_p, of the 20 variances $Var_1,\ldots,Var_{20}$.

$$Var_p = \frac{(n_1-1)\ Var_1 + \cdots + (n_{20}-1)\ Var_{20}}{\sum_{j=1}^{20} (n_j-1)}$$

Step 6: Calculate the pooled standard deviation, SD_p.

$$SD_p = \sqrt{Var_p}$$

Step 7: From a table of tolerance factors, K, for two-sided tolerance intervals with 95% probability and 95% coverage, obtain K for $(\sum n_j-20)$ degrees of freedom for the approximately 60 increments per replicate, K = 2.04. This value corresponds to a total of 900 degrees of freedom and can be used unless the number of differences obtained is less than 600. (Reference: *CRC Handbook of Tables for Probability and Statistics*. 1966. William H. Beyer (ed.). pp. 31-35. The Chemical Rubber Company.)

Step 8: Calculate the minimum water level change, MLC, that the sensor can detect.

$$MLC = K\ SD_p$$

or

$$MLC = 2.04\ SD_p$$

The result, MLC, is an estimate of the minimum water level change that the water sensor can detect.

7.2.3 Time to Detect an Increase in Water Level

The minimum detectable water level and the minimum detectable change can be used to estimate the minimum time needed to detect water incursion into the tank at a specified rate. This time is specific to each tank size and geometry and depends on specific assumptions. The calculations are illustrated for an 8,000-gallon steel tank that is 96-inch diameter and 256 inches long.

Suppose there are x inches of water in the tank. The tank is made of quarter-inch steel, so the inside diameter is 95.5 inches, giving a radius, r, of 47.75 inches and a length of 255.5 inches. The water surface will be 2d wide, where d, in inches, is calculated as

$$d = \sqrt{r^2 - (r - x)^2},$$

where x is the water depth. The area of the water surface at depth of x inches of water is then given by 255.5 x 2d $inch^2$. Multiplying this by the minimum level change and dividing the result by 231 $inch^3$ per gallon gives approximately the volume change in gallons that the sensor can detect reliably. This differs with the level of water in the tank.

For these calculations, the following assumptions are used. The probe is assumed to be inserted at the midpoint of the tank length and to rest on a striker plate the top of which is 0.63 inch above the bottom of the tank. The initial water depth is taken as the minimum depth the sensor can detect with 95% probability plus the striker plate depth of 0.63 inch, rounded up to the next quarter inch. The tank is assumed level. (Calculations show that if the tank is tilted, the cross-sectional area of the water surface will be slightly less for the same water depth at this location, so these calculations slightly overestimate the volume.)

To determine how long the method will take to detect a water incursion at the rate of 0.10 gallon per hour, divide the minimum volume change that the water sensor can detect by 0.10 gallon per hour. As a numerical example, suppose the minimum depth of the water detectable is 0.3 inch and the minimum detectable change is 0.02 inch. This gives x = 0.95 inch (0.3 + 0.625 rounded up). In an 8,000-gallon tank with inside diameter 95.5 inches and length 255.5 inches, the water surface width, d, is calculated as

$$d = \sqrt{(47.75)^2 - (46.8)^2} = 9.48 \text{ inches}$$

The volume, in gallons, corresponding to a 0.02-inch increase is

$$V = 2(9.48) \times 255.5 \times (0.02)/231$$

or

$$V = 0.42 \text{ gallon}$$

The time that the sensor will take to detect water incursions at the rate of 0.10 gallon per hour will be

$$\text{time} = 0.42 \text{ gallon}/0.10 \text{ gallon per hour} = 4.2 \text{ hours}$$

Thus, the sensor would detect water coming in at the rate of 0.10 gallon per hour after about 4 hours 15 minutes. The incursion of the water into the tank should be obvious under these conditions if the test is run for at least 4 hours 15 minutes.

The minimum amount of water in a tank that can be detected by a sensor depends on the placement of the sensor, any tilt of the tank, the tank size, and the sensor threshold. This minimum amount varies from about 2 gallons to 10 or 15 gallons, depending on the combination of these factors. If water enters at a rate of 0.10 gallon per hour, it would require anywhere from a day to a week for enough water to be detected, starting with no water in the tank.

7.3 OTHER REPORTED CALCULATIONS

This section describes other calculations needed to complete the Results of U.S. EPA Standard Evaluation form (Appendix B). Most of these calculations are straightforward and are described here to provide complete instructions for the use of the results form.

These sections are only required if they are applicable to the particular nonvolumetric method being evaluated. If a section is not applicable, skip the calculations and report "not applicable" on the results form.

Size of Tank

The evaluation results are applicable to tanks up to at most 50% larger capacity than the test tank and to all smaller tanks. Multiply the volume of the test tank by 1.50. Round this number to the nearest 100 gallons and report the result on page 2 of the results form.

Maximum Allowable Temperature Difference

This section is only applicable if temperature conditioning was needed and used as part of the evaluation procedure. If temperature does not affect the operation of the method, ignore this section and indicate "not applicable" on the results form.

Calculate the standard deviation of the 21 temperature differences actually achieved during testing. Multiply this number by the factor ± 1.5 and report the result as the temperature range on the limitations section of the results form.

The nominal temperature difference of 5°F used in the design was obtained from data collected on the national survey (Flora, J. D., Jr., and J. E. Pelkey, "Typical Tank Testing Conditions," EPA Contract No. 68-01-7383, Work Assignment 22, Task 13, Final Report, December 1988). This difference was approximately the standard deviation of the temperature differences observed in the tank tests conducted during the national survey. The factor 1.5 is a combination of two effects. One effect results from scaling up the standard deviation of the design temperature differences to 5°F. The second effect results from using the rule that about 80% of the temperature differences on tank tests are expected to be within ± 1.282 times the standard deviation.

Average Waiting Time After Filling

Calculate the average of the time intervals between the end of the filling cycle and the start of the test for the 21 tests that started immediately after the specified waiting time. (Note: If more than 21 tests are done immediately after the filling, use all such tests. However, do not use the time to the start of the second test in a pair as this would give a misleading waiting time.) Report this average time as the waiting time after adding product on the results form. Note: The median may be used as the average instead of the mean if there are atypical waiting times.

For tracer methods, the average waiting time may more appropriately be the time from adding the tracer to the tank until the completion of the test.

Average Waiting After "Topping Off"

If the method fills the tank up into the fill pipe, calculate the average time interval between the time when the final topping off was completed and the start of the test. Calculate this average using data from all tests when this step was performed. Report the result on the results form as the waiting time after "topping off" to the final testing level. If this step is not performed (e.g., for a test with the tank at 95% of capacity), enter NA (not applicable) in the appropriate space on the results form. Note: The median may be used instead of the mean if there are some atypical waiting times.

Average Data Collection Time Per Test

Use the duration of the data collection phase of the tests to calculate the average data collection time for the total number (at least 42) of tests. Report this time as the average data collection time per test.

Product Level

If all tests are done at the same product level, report that level on the results form. If testing was done at different levels, report the applicable product level as the acceptable range (e.g., from 60% to 90% full) used in the testing.

Minimum Total Testing Time

Finally, calculate an average total test time from the test data. This is the time it would take from the time the test crew arrives at the site until a test is completed, the equipment dismantled, and the tank returned to service. Typically, it will be the time from initial setup of equipment through the first test data collection, plus the time required to dismantle the equipment. Report this total time lapse on the results form as the minimum time that the tank can be expected to be out of service for a test of this type.

The intent of this is to provide an estimate of the time that the testing will interfere with normal operation of the tank. The nonvolumetric methods will differ in those parts of their operation that require the tank to be out of service. Consequently, the time that should be reported here is the estimated time for which testing with this method will interfere with the use of the tank by requiring that it be out of service.

7.4 SUPPLEMENTAL CALCULATIONS AND DATA ANALYSES (OPTIONAL)

This section discusses some additional data analyses that may be possible with the data, depending on the actual results. It also provides some rationale for the sample size selection.

7.4.1 One-Sided Confidence Limits on P(FA) and P(D)

It is possible to estimate the false alarm rate and probability of detection directly as done in Section 7.1 with any sample size. However, for fewer than 20 tests, the estimate of P(FA) will be zero or will exceed 5%, depending on whether any false alarms are found. Similarly, P(D) will be 100% or less than 95% for sample sizes less than 20 depending on whether any leaks are missed or not. Thus, the sample size of 20 is the smallest that allows for one mistake in each case and still provides estimated performance meeting the EPA standards. The sample size of 21 was chosen from experimental design considerations to balance the different conditions.

Confidence limits for P(FA) and P(D) can be calculated based on the observed results and the sample sizes. The formulas for perfect scores were given in Section 7.1.1 for P(FA) and in Section 7.1.2 for P(D). These also depend on the selected confidence coefficient. Table 3 below gives 90% and 95% one-sided confidence limits for P(FA) and P(D) based on samples of 21 tests for the case of no mistakes and one mistake, the two conditions under which the method meets the EPA performance standards if evaluated with the minimum 21 tests.

Table 3. ONE-SIDED CONFIDENCE LIMITS FOR P(FA) AND P(D)

Field test results	Confidence coefficient 90%	Confidence coefficient 95%
0 Error out of 21	$P(FA) \leq 0.104$	$P(FA) \leq 0.133$
1 Error out of 21	$P(FA) \leq 0.173$	$P(FA) \leq 0.207$
0 Error out of 21	$P(D) \geq 0.896$	$P(D) \geq 0.867$
1 Error out of 21	$P(D) \geq 0.827$	$P(D) \geq 0.793$

Table 3 shows that the confidence limits start to become fairly large for high confidence with even one error. Using a larger sample size would improve the confidence limits, but would add significantly to the cost of testing. The sample sizes were selected as a compromise to provide reasonable estimates while not requiring excessively expensive testing.

7.4.2 Alternative Statistical Model

If the evaluation uses three non-zero leak rates and if the method fails to detect some of the induced leaks, an alternative statistical analysis may be possible. This alternative statistical method fits a logistic model to the data, assuming that the probability of detecting a leak increases with the size of the leak. If one assumes that the logistic model with parameters A and B holds, then the probability of detecting a leak can be expressed as:

$$P[\text{Detecting a leak given a leak of size } S] = 1/[1+\exp(A+BS)]$$

That is, the probability that the test method will indicate a leak when there is an actual induced leak rate, S, is given by the logistic function. The data from all 42 tests can be used to estimate the parameters A and B of the equation. This requires an iterative estimation technique that is available in several commercial statistical software packages such as SAS, BMDP, or SYSTAT. The estimation will not converge if no mistakes are made, and it may not converge if only a few mistakes are made. If the estimates do converge, then the function with the estimated values of A and B can be used to estimate the P(FA) of the method by substituting S = 0. The P(D) can be estimated for any leak rate S by substituting S into the equation. Specifically, S = 0.10 gallon per hour can be substituted to compare with the EPA performance standards for probability of detection.

7.4.3 Estimation of Temperature Effect

If the temperature and stabilization time variables influence the operation of the test and testing is done according to the full set of conditions in Table 1, the logistic model can also be used to test whether the additional variables did have a significant effect on the performance. Again, whether this is possible depends on the number and pattern of the actual data results. The approach is to add one or more indicator variables to the logistic model to estimate the effect of the additional factor. The model would become

$$P[\text{Detecting a leak given a leak of size } S] = 1/[1+\exp(A+BS+C_iT_i)]$$

where the three temperature conditions were identified by T_i and coded appropriately. This modeling becomes rather involved. The evaluating organization should involve statistical support if these additional calculations are warranted. Note that this modeling will generally not be possible if the system performs so well that the direct estimates of P(FA) and P(D) described in Section 7.1 meet the EPA performance standards. Thus, this approach is supplemental to provide information for a vendor to use in improving a method by identifying factors that significantly affect the system's performance.

SECTION 8

INTERPRETATION

The results reported are valid for the experimental conditions during the evaluation, which have been chosen to represent situations commonly encountered in the field. These should be typical of most tank testing conditions, but extreme conditions can occur and might adversely affect the performance of the method. It should be emphasized that the performance estimates are based on average results obtained in the tests. An individual test may not do as well. Some individual tests may do better.

8.1 BASIC PERFORMANCE ESTIMATES

The relevant performance measures for proving that a tightness test method meets EPA standards are the P(FA) and P(D) for a leak rate of 0.10 gallon per hour. The estimated P(FA) can be compared with the EPA standard of P(FA) not to exceed 5%. In general, a lower P(FA) is preferable, since it implies that the chance of mistakenly indicating a leak on a tight tank is less. For a concern with many tanks, there will be fewer false alarms. However, reducing the false alarm rate may also reduce the chance of detecting a leak. The probability of detection generally increases with the size of the leak. The EPA standard specifies that P(D) be at least 95% for a leak of 0.10 gallon per hour. A higher estimated P(D) means that there is less chance of missing a small leak.

The discrete nature of the data implies that only a few values of P(FA) or P(D) are possible. With the standard 21 tests for each test condition (tight or leaking tank), the possible values are 0, 1/21, 2/21, etc. Consequently, the reported estimates are only precise to about 5%. The confidence limits reported in the case of a perfect score indicate the range in which the true P(FA) or P(D) is expected to be. For example, a method that achieved zero false alarms out of 21 would not be expected to have a zero false alarm rate. Instead, its false alarm rate should be less than 10.4% with 95% confidence.

If testing is done at an induced lak rate less than 0.10 gallon per hour, the P(D) may be reported at the smaller leak rate actually used. The standard test, using an induced leak rate of 0.10 gallon per hour, would report P(D) for the rate of 0.10 gallon per hour. In general, a method that can detect a smaller leak with high probability is to be preferred because it will identify a potential problem earlier. This may reduce the amount of pollution and the cost of remedial action.

8.2 LIMITATIONS

Nonvolumetric tank tightness testing methods that are based on different operating principles will have different factors that can interfere with their performance. Consequently, the limitations on the applicability of the performance estimates will also vary with the method. If a factor, for example temperature, does not affect the principle of operation, it should not be reported as a limitation. However, there may be interfering factors other than those listed in the experimental plan that affect a particular test method. If so, those additional factors might limit the applicability of the method. The reporting form provides a place to identify other sources of interference and to state the test conditions for them.

Some nonvolumetric test methods use more than one mode of operation. If so, different limitations may apply to each mode of leak detection. It is possible that one mode of operation may be unaffected by size of tank, but that another may depend strongly on tank size. For example, a water sensor may be used to test for leaks in the presence of a high ground-water level. It may do so by sensing water incursion, in which case it must be able to detect water incursion at the rate of 0.10 gallon per hour. Since the time required for the water level to be detectable at a fixed rate of incursion will be a function of the size of the tank, this mode of leak detection is dependent on tank size.

8.3 WATER LEVEL DETECTION FUNCTION

If the system uses a water level sensor, the following results are reported.

The minimum water level detected by the sensor is estimated from the average threshold of detection, and the variability of the water level threshold is estimated by the standard deviation of the test data. The minimum water level that will be detected at least 95% of the time is the level to be reported. Statistically, this is a one-sided tolerance limit.

The tolerance limit calculated in Section 7.2.1 estimates the minimum water level that the sensor can detect above the bottom of the probe. If the installation of the sensor leaves the probe at a specified distance above the bottom of the tank (for example, 1 inch), then this minimum distance needs to be added to the reported minimum detectable water level.

8.4 MINIMUM WATER LEVEL CHANGE MEASUREMENT

The water sensor may be used to test for leaks in the event of a high ground-water level. If the ground-water level is above the bottom of the tank, there will be an inward pressure when the product level is sufficiently low, and if there is a hole in the tank, water will flow into the tank under these conditions. Based on the ability of the water sensor to detect a change in the level of water in the product, one can determine how much water must enter the tank in order for an increase in the water level to be detected. From this information, in turn, one can determine the size of a leak of water into the tank that the system can detect at a given time.

The standard deviation of the differences between the change in water level measured by the sensor and the change induced during the tests is used to determine the ability of the water level sensor to detect changes in the water level. A two-sided 95% tolerance interval is then calculated for this detection ability (Section 7.2.2).

The minimum change in water level that can be detected is used to compute a minimum change in water volume in the tank. This conversion is specific to the tank size. Using the minimum change in water volume that the sensor can detect, the time needed for the method to detect an incursion of water at the rate of 0.10 gallon per hour is calculated (Section 7.2.3). This calculation indicates the minimum time needed for the water detector to identify an inflow of water at the minimum leak rate and to alert the test operator that the water level has increased.

8.5 ADDITIONAL CALCULATIONS

If the performance estimates do not meet the performance requirements, the vendor may want to investigate the conditions under which errors occurred. Calculating the percent of errors by size of leak, by temperature condition, and by length of stabilization time as applicable may suggest ways to improve the method. This may be as straightforward as identifying conditions that lead to poor performance and revising the operating procedure to avoid those, or it may require redesign of the method.

The relationship of performance to test conditions is primarily of interest when the method does not meet the EPA performance standards. Developing these relationships is part of the optional or supplementary data analysis that may be useful to the vendor, but not to many tank owners or operators.

SECTION 9

REPORTING OF RESULTS

Appendix B is designed to be the framework for a standard report. There are five parts to Appendix B, each of which is preceded by instructions for completion. The first part is the Results of U.S. EPA Standard Evaluation form. This is basically an executive summary of the findings. It is designed to be used as a form that would be provided to each tank owner/operator that uses this system of leak detection. Consequently, it is quite succinct. The report should be structured so that this results form can be easily reproduced for wide distribution.

A method that uses more than one mode of leak detection may achieve different performance results for the different modes of operation. The results form is structured to allow for reporting the P(FA) and P(D) separately for different modes of leak detection. The method meets the EPA performance requirements only if all modes of leak detection meet those requirements.

Suppose that a method had two modes of testing, a basic one and an ancillary one for testing in the presence of a high ground-water level. Suppose that the test method when evaluated in the case of high ground-water level did not meet the EPA performance requirements, but the basic one did. Then a report could be issued, stating that the method meets the EPA performance requirements, but cannot test when the ground-water level is above the bottom of the tank.

The statement of compliance with the EPA performance standards must be consistent with stated limitations on the form and also with the standard operation of the method as described on the Description form.

The second part of the standard report consists of the Description of the method. A description form is included in Appendix B and should be completed by the evaluating organization assisted by the vendor.

The third part of the standard report contains a Reporting Form for Leak Test Results, also described in Appendix B. This table summarizes the test results and contains the information on starting dates and times, test duration, leak test results, etc.

The fourth part of Appendix B contains a blank Individual Test Log. While the Individual Test Log has been designed to be flexible, it may need modifications for some test methods. This form should be reproduced and used to record data in the field. Copies of the completed daily test logs are to be included in the standard report. These serve as the backup data to document the performance estimates reported.

The fifth part of Appendix B provides a form to record the test results when evaluating the system's water sensor. The data to be recorded follow the testing protocol (in Section 6.5) to determine the minimum level of water and the minimum water level change that the system can detect. This part is only applicable if the system uses a water sensor.

If the optional calculations described in Section 7.4 are performed, they should be reported to the vendor. It is suggested that these results be reported in a separate section of the report, distinct from the standard report. This would allow a user to identify the parts of the standard report quickly while still having the supplemental information available if needed.

The limitations on the results of the evaluation are to be reported on the Results of U.S. EPA Standard Evaluation form. The intent is to document that the results are valid under conditions represented by the test conditions. Section 7.3 describes the summary of the test conditions that should be reported as limitations on the results form. These items are also discussed below. The test conditions have been chosen to represent the majority of testing situations, but do not include the most extreme conditions under which testing could be done. The test conditions were also selected to be practical and not impose an undue burden for evaluation on the test companies.

One practical limitation of the results is the size of the tank. Tests based on volumetric changes generally perform less well as the size of the tank increases. However, for some nonvolumetric test methods, size is not such a restriction. The evaluating organization must determine the extent to which tank size affects performance and report a size limitation here.

A second potential limitation on the results is the temperature differential between the product added to the tank and that of the product already in the tank. Testing during the EPA national survey (Flora, J. D., Jr., and J. E. Pelkey, "Typical Tank Testing Conditions," EPA Contract No. 68-01-7383, Work Assignment 22, Task 13, Final Report, December 1988) found that temperature differentials were no more than 5°F for at least 60% of the tests. However, it is clear that larger differences could exist. If temperature affects the method, then the temperature differences used in the evaluation must be reported. If the physical principle of the method is not affected by temperature, then report that the method is not limited by temperature and the basis for this conclusion. The evaluation testing may be done using larger temperature differentials, reporting those actually used. The results cannot be guaranteed for temperature differentials larger than those used in the evaluation.

A third limitation on the results is the time needed by the method for its operation. For example, tracer methods require some time for the tracer to move through the backfill to the sensors. The Individual Test Logs call for recording the actual time used in the testing. The average time is to be reported and the results should be valid for times at least this long. It may be the case for some nonvolumetric methods that the time for preparation does not require taking the tank out of service. If so, this should be noted.

The duration of the data collecting phase of the test is another limitation of the method. If a test shortens the data collection time and so collects less data, this may adversely affect the method's performance. As a consequence, the results do not apply if the data collection time is shortened. This is primarily of concern in documenting that a tank is tight. If results clearly indicate a leak, this may sometimes be ascertained in less time than needed to document a tight tank, particularly if the leak rate is large. Thus, while the false alarm rate may be larger if the test time is shortened, this is not usually a problem in that if test results indicate a leak, efforts are usually made to identify and correct the source of the leak.

If the method uses a water detector as part of its operation, the minimum depth of water that the sensor can detect is reported. In addition, the minimum change in water level that the sensor can detect is reported. From this minimum detectable change in water level, a minimum volume change can be calculated based on the tank size and depth of the water. A minimum time for detection is calculated and reported as the time needed for water flowing into the tank at the rate of 0.10 gallon per hour to increase the water volume enough to be detected by the sensor.

It is expected that nonvolumetric methods may require some modification of the forms. It is hoped that the forms supplied will be flexible enough to provide for most of the data recording needs. However, if modifications are needed to accommodate a particular method, the evaluating organization should make the required modifications and use the resulting forms. The conditions during the evaluation tests are to be recorded. The factors that affect the performance of the method being evaluated must be recorded. The performance results are limited by the test conditions actually used and reported.

APPENDIX A

DEFINITIONS AND NOTATIONAL CONVENTIONS

In this protocol leaks are viewed as product lost from the tank. As a convention, leak rates are positive numbers, representing the amount of product loss per unit time. Thus a larger leak represents a greater product loss. Parts of the leak detection industry report volume changes per unit time with the sign indicating whether product is lost from the tank (negative sign) or is coming into the tank (positive sign). We emphasize that here, leaks refer to the direction out of the tank and the rate to the magnitude of the flow.

The performance of a leak detection method is expressed in terms of the false alarm rate, P(FA), and the probability of detecting a leak of specified size, P(D(R)), where R is the leak rate. In order to understand these concepts, some explanation is helpful.

Nonvolumetric test methods make a determination of whether a tank is leaking or not. The false alarm rate is the proportion of times that the method would incorrectly indicate that a tight tank is leaking. The probability of detection is the probability that the method will correctly identify a leak of specified size, R. Usually, the larger the leak rate, the more likely the method is to detect it, so the probability of detection must specify the leak rate to be detected. In evaluating nonvolumetric methods, the performance measures are generally estimated directly from the test results. The false alarm rate is estimated by conducting a number of trials on a tight tank and calculating the proportion of those during which the method incorrectly indicates a leak. The probability of detection is estimated by conducting a series of trials with an induced leak rate, R, and calculating the proportion of those trials during which the method correctly identifies the tank as leaking.

Definitions of some of the terms used throughout the protocol are presented next.

Nominal Leak Rate: The set or target leak rate to be achieved as closely as possible during testing. It is a positive number in gallon per hour.

Induced Leak Rate: The actual leak rate, in gallon per hour, used during testing, against which the results from a given test device will be compared.

False Alarm: Declaring that a tank is leaking when in fact it is tight.

Probability of False Alarm, P(FA): The probability of declaring a tank leaking when it is tight. In statistical terms, this is also called the Type I error and is denoted by alpha (α). It is usually expressed in percent, say, 5%.

Probability of Detection, P(D(R)): The probability of detecting a leak rate of a given size, R gallon per hour. In statistical terms, it is the power of the test method and is calculated as one minus beta (β), where beta is the probability of not detecting (missing) a leak rate R. Commonly the power of a test is expressed in percent, say, 95%.

Resolution: The resolution of a measurement system is the least change in the quantity being measured which the system is capable of detecting.

APPENDIX B

REPORTING FORMS

Appendix B provides five sets of blank forms. Once filled out, these forms will provide the framework for a standard report. They consist of the following:

1. **Results of U.S. EPA Standard Evaluation--Nonvolumetric Tank Tightness Testing Method** (four pages)

2. **Description--Nonvolumetric Tank Tightness Testing Method** (six pages)

3. **Reporting Form for Leak Test Results--Nonvolumetric Tank Tightness Testing Method** (three pages)

4. **Individual Test Log--Nonvolumetric Tank Tightness Testing Method** (five pages)

5. **Reporting Form for Water Sensor Evaluation Data--Nonvolumetric Tank Tightness Testing Method** (four pages)

Each set of forms is preceded by instructions on how the forms are to be filled out and by whom. The following is an overview on various responsibilities.

Who is responsible for filling out which form?

1. **Results of U.S. EPA Standard Evaluation.** The **evaluating organization** is responsible for completing this form at the end of the evaluation.

2. **Description of Nonvolumetric Tank Tightness Testing Method.** The **evaluating organization** assisted by the **vendor** will complete this form by the end of the evaluation.

3. **Reporting Form for Leak Test Results.** This form is to be completed by the **evaluating organization.** In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for that form will consist of the field test results recorded by the evaluating organization's field crew on the Individual Test Logs (below) and the vendor's test results.

4. **Individual Test Logs.** These forms are to be used and completed by the **evaluating organization's field crew.** These forms need to be kept blind to the vendor during testing. It is recommended that the evaluating organization reproduce a sufficient number (at least 42 copies) of the blank form provided in this appendix and produce a bound notebook for the complete test period.

   It is expected that nonvolumetric methods may require some modification of the test log. The form provided in this appendix was designed from a volumetric test log. It is the responsibility of the evaluating organization to design the appropriate forms with the vendor's input. It is important to include in the test logs all parameters relevant to the evaluation of a specific method. In particular, it is necessary to document the induced leaks.

5. **Reporting Form for Water Sensor Evaluation Data.** These forms provide a template for the water sensor evaluation data if the method includes such a leak detection mode. The forms are to be used and completed by the **evaluating organization's field crew.** It is recommended that the evaluating organization reproduce a sufficient number (at least 20 copies) of the blank form provided in this appendix and produce a bound notebook to be used in the field.

At the completion of the evaluation, the evaluating organization will collate all the forms into a single **Standard Report** in the order listed above. In those cases where the evaluating organization performed additional, optional calculations (see Section 7.4 of the protocol), these results may be attached to the standard report. There is no reporting requirement for these calculations, however.

Distribution of the Evaluation Test Results

The organization performing the evaluation will prepare a report for the vendor describing the results of the evaluation. This report consists primarily of the forms in Appendix B. The first form reports the results of the evaluation. This four-page form is designed to be distributed widely. A copy of this four-page form will be supplied to each tank owner/operator who uses this method of leak detection. The owner/operator must retain a copy of this form as part of his record keeping requirements. The owner/operator must also retain copies of each tank test performed at his facility to document that the tank(s) passed the tightness test. This four-page form will also be distributed to regulators who must approve leak detection methods for use in their jurisdiction.

The complete report, including all the forms in Appendix B, will be submitted by the evaluating organization to the vendor of the leak detection method. The vendor may distribute the complete report to regulators who wish to see the data collected during the evaluation. It may also be distributed to customers of the leak detection method who want to see the additional information before deciding to select a particular leak detection method.

The optional part of the calculations (Section 7.4), if done, would be reported by the evaluating organization to the vendor of the leak detection method. This is intended primarily for the vendor's use in understanding the details of the performance and perhaps suggesting how to improve the method. It is left to the vendor whether to distribute this form, and if so, to whom.

The evaluating organization of the leak detection method provides the report to the vendor. Distribution of the results to tank owner/operators and to regulators is the responsibility of the vendor.

The forms, each preceded by its instructions for completion, are presented next.

Results of U.S. EPA Standard Evaluation
Nonvolumetric Tank Tightness Testing Method

Instructions for completing the form

This 3-page form is to be filled out by the evaluating organization upon completion of the evaluation of the method. This form will contain the most important information relative to the method evaluation. All items are to be filled out and the appropriate boxes checked. If a question is not applicable to the method, write "NA" in the appropriate space.

This form consists of six main parts. These are:

1. Method Description
2. Evaluation Results
3. Test Conditions During Evaluation
4. Limitations on the Results
5. Certification of Results
6. Additional Evaluation Results (if applicable)

Method Description

Indicate the commercial name of the method, the version, and the name, address, and telephone number of the vendor. Some vendors might use different versions of their method when using it with different products or tank sizes. If so, indicate the version used in the evaluation. If the vendor is not the party responsible for the development and use of the method, then indicate the home office name and address of the responsible party.

Evaluation Results

The evaluation results must be reported separately for each detection mode if the method operates in different detection modes depending on field conditions. Describe the mode of detection for which the results are applicable.

P(FA) is the probability of false alarm as calculated in Section 7.1.1.

Report the number of false alarms and the number of tight tank tests, and report the 95% confidence interval based on the binomial distribution with N_1 tests. Some values are tabled on page 48.

The leak rate used in the evaluation is to be inserted in the blank. This is the leak rate corresponding to the reported P(D) below.

P(D) is the probability of detecting a leak of the size induced (no more than 0.10 gallon per hour) as calculated in Section 7.1.2.

Report the number of correct detections and the number of simulated leak tests, and report the 95% confidence interval based on the binomial distribution with N_2 tests. Some values are tabled on page 48.

If the calculated P(FA) is 5% or less and if the calculated P(D) is 95% or more, then check the "does" box. Otherwise, check the "does not" box. Note: the P(FA) and P(D) requirements apply to <u>each</u> leak detection mode used by the method.

Indicate whether this method operates under more than one mode of detection. Check the appropriate box and complete page 4 (Additional Evaluation Results) if applicable.

Test Conditions During Evaluation

Insert the information in the blanks provided. The nominal volume of the tank in gallons is requested as is the tank material, steel, or fiberglass. Also report the backfill material in the tank excavation, e.g., clean sand or pea gravel. Give the tank diameter and length in inches. Report the product used in the testing. Give the range of temperature differences actually measured as well as the standard deviation of the observed temperature differences. Report the ground water level for the test tank in inches above the bottom of the tank. Report zero for ground water at or below the bottom of the tank.

Other sources of interference may affect non-volumetric methods. Report any sources of interference specific to the method on the lines provided. Also report the range of test conditions for the indicated interference source. If no additional sources of interference were identified, check "None."

Limitations on the Results

The size (gallons) of the largest tank to which these results can be applied may be calculated as 1.50 times the size (gallons) of the test tank.

The temperature differential, the waiting time after adding product until testing, and the total data collection time should be completed using the results from calculations in Section 7.1.4. Alternately, if the principle of operation of the method is not affected by product temperature changes, check the box indicating that temperature is not a limiting factor and give the justification.

Certification of Results

Here, the responsible person at the evaluating organization indicates which test procedure was followed and provides his/her name and signature, and the name, address, and telephone number of the organization.

Additional Evaluation Results (if applicable)

If the "yes" box relating to other leak detection modes on page 1 was checked, then provide the necessary information for the P(FA) and P(D) for the additional leak detection mode. These probabilities will have been calculated as described in Sections 7.1.1 and 7.1.2, based on the evaluation results obtained in that detection mode.

Fill out this section as described on page B-5.

If the method includes a water sensor, then complete the results for that sensor.

The minimum detectable water level and the minimum detectable level change that the sensor can detect will have been obtained from the calculations in Sections 7.2.1 and 7.2.2.

The minimum time for the water sensor to detect a leak of 0.10 gallon per hour by detecting an increase in the water level in the tank will have been obtained from the calculations in Section 7.2.3. This time is calculated based on a water depth equal to the striker plate height plus the minimum detectable water level (above the striker plate). It assumes a level tank and that the sensor is located midway along the tank length. The minimum detectable increase is used to calculate the volume change needed. This volume is divided by 0.10 gallon per hour to get the time reported. Indicate the size of the tank on which this time calculation is based.

Results of U.S. EPA Standard Evaluation

Nonvolumetric Tank Tightness Testing Method

This form tells whether the tank tightness testing method described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Nonvolumetric Tank Tightness Testing Methods." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

Method Description

Name ______________________________

Version ______________________________

Vendor ______________________________

____
(street address)

____
(city) (state) (zip) (phone)

Evaluation Results

This method, which declares a tank to be leaking when ______________________________

____

has an estimated probability of false alarms [P(FA)] of ________% based on the test results of ________ false alarms out of ________ tests. A 95% confidence interval for P(FA) is from

________ to ________%.

The corresponding probability of detection [P(D)] of a ________ gallon per hour leak is ________% based on the test results of ________ detections out of ________ simulated leak tests. A 95% confidence interval for P(D) is from ________ to ________%.

Does this method use additional modes of leak detection? ☐ Yes ☐ No. If Yes, complete additional evaluation results on page 3 of this form.

Based on the results above, and on page 3 if applicable, this method ☐ does ☐ does not meet the **federal** performance standards established by the U.S. Environmental Protection Agency (0.10 gallon per hour at P(D) of 95% and P(FA) of 5%).

Test Conditions During Evaluation

The evaluation testing was conducted in a ________ -gallon ☐ steel ☐ fiberglass tank that was ________ inches in diameter and ________ inches long, installed in ________________ backfill.

The ground-water level was ________ inches above the bottom of the tank.

Test Conditions During Evaluation (continued)

The tests were conducted with the tank ________ percent full.

The temperature difference between product added to fill the tank and product already in the tank ranged from ________°F to ________°F, with a standard deviation of ________°F.

The product used in the evaluation was ________________.

This method may be affected by other sources of interference. List these interferences below and give the ranges of conditions under which the evaluation was done. (Check None if not applicable.)

☐ None

Interferences	Range of Test Conditions
________________	________________
________________	________________
________________	________________

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for using the method are followed.
- The tank contains a product identified on the method description form.
- The tank capacity is ________ gallons or smaller.
- The difference between added and in-tank product temperatures is no greater than + or - ________ degrees Fahrenheit.

  ☐ Check if applicable:
  Temperature is not a factor because ________________________________

  ____
- The waiting time between the end of filling the test tank and the start of the test data collection is at least ________ hours.
- The waiting time between the end of "topping off" to final testing level and the start of the test data collection is at least ________ hours.
- The total data collection time for the test is at least ________ hours.
- The product volume in the tank during testing is ________% full.
- This method ☐ can ☐ cannot be used if the ground-water level is above the bottom of the tank.

Other limitations specified by the vendor or determined during testing:

____

____

Nonvolumetric TTT Method____________________
Version____________________

> **Safety disclaimer: This test procedure only addresses the issue of the method's ability to detect leaks. It does not test the equipment for safety hazards.**

Additional Evaluation Results (if applicable)

This method, which declares a tank to be leaking when ____________________

____

has an estimated probability of false alarms [P(FA)] of ________% based on the test results of ________ false alarms out of ________ tests. **Note**: A perfect score during testing does not mean that the method is perfect. Based on the observed results, a 95% confidence interval for P(FA) is from 0 to ________%.

The corresponding probability of detection [P(D)] of a ________ gallon per hour leak is ________% based on the test results of ________ detections out of ________ simulated leak tests. **Note:** A perfect score during testing does not mean that the method is perfect. Based on the observed results, a 95% confidence interval for P(D) is from 0 to ________%.

> **Water detection mode (if applicable)**

Using a false alarm rate of 5%, the *minimum water level* that the water sensor can detect with a 95% probability of detection is ________ inches.

Using a false alarm rate of 5%, the *minimum change in water level* that the water sensor can detect with a 95% probability of detection is ________ inches.

Based on the minimum water level and change in water level that the water sensor can detect with a false alarm rate of 5% and a 95% probability of detection, the *minimum time* for the system to detect an increase in water level at an incursion rate of 0.10 gallon per hour is ________ minutes in a ________-gallon tank.

Certification of Results

I certify that the nonvolumetric tank tightness testing method was installed and operated according to the vendor's instructions. I also certify that the evaluation was performed according to the standard EPA test procedure for nonvolumetric tank tightness testing methods and that the results presented above are those obtained during the evaluation.

____________________ (printed name)	____________________ (organization performing evaluation)
____________________ (signature)	____________________ (city, state, zip)
____________________ (date)	____________________ (phone number)

Description of Nonvolumetric Tank Tightness Testing Method

Instructions for completing the form

This 6-page form is to be filled out by the evaluating organization with assistance from the vendor, as part of the evaluation of the method. This form provides supporting information on the principles behind the system or on how the equipment works.

To minimize the time to complete this form, the most frequently expected answers to the questions have been provided. For those answers that are dependent on site conditions, please give answers that apply in "typical" conditions. Please write in any additional information about the testing method that you believe is important.

There are seven parts to this form. These are:

1. Method Name and Version
2. Product
   > Product type
   > Product level
3. Principle of Operation
4. Temperature Measurement
5. Data Acquisition
6. Procedure Information
   > Waiting times
   > Test duration
   > Total time
   > Other important elements of the procedure or method
   > Identifying and correcting for interfering factors
   > Interpreting test results
7. Exceptions

Indicate the commercial name and the version of the method in the first part.

NOTE: The version is provided for methods that use different versions of the equipment for different products or tank sizes.

For the six remaining parts, check all appropriate boxes for each question. Check more than one box per question if it applies. If a box "Other" is checked, please complete the space provided to specify or briefly describe the matter. If necessary, use all the white space next to a question for a description.

The section "**> Other important elements of the procedure or method**" should be completed carefully. List here any other important elements of the procedure or method that could affect its performance. For example:

- If the pressure in the ullage space is different from atmospheric during testing, indicate whether a negative or positive pressure was applied. Report that pressure and its units.

- If the method used is a tracer method, clearly document the process of adding the tracer to the tank and in the spiking port.

- If a tracer is added to the product in the tank, provide information on the following items:
  * type of tracer(s)
  * tracer concentration in the product
  * type of carrier
  * time between spiking and starting the test
  * type of sampling, e.g., whether sampling is active or passive (in other words, how does the tracer reach the sampling ports? by natural diffusion process? is the process enhanced by adding forced air? etc.)
  * other relevant items

- When sampling ports are installed for tracer methods, measure the distances between any part of the tank to its nearest sampling port. Report the largest of these distances.

Description

Nonvolumetric Tank Tightness Testing Method

This section describes briefly the important aspects of the nonvolumetric tank tightness testing method. It is not intended to provide a thorough description of the principles behind the method or how the equipment works.

Method Name and Version

____

Product

> Product type

For what products can this method be used? (check all applicable)

- ☐ gasoline
- ☐ diesel
- ☐ aviation fuel
- ☐ fuel oil #4
- ☐ fuel oil #6
- ☐ solvents
- ☐ waste oil
- ☐ other (list) ________________________________

> Product level

What product level is required to conduct a test?

- ☐ above grade
- ☐ within the fill pipe
- ☐ greater than 90% full
- ☐ greater than 50% full
- ☐ empty
- ☐ other (specify) ____________________________

Principle of Operation

What principle or principles are used to identify a leak?

- ☐ acoustical signal characteristic of a leak
- ☐ identification of a tracer chemical outside the tank system
- ☐ changes in product level or volume
- ☐ detection of water inflow
- ☐ other (describe briefly) ____________________

Temperature Measurement

If product temperature is measured during a test, how many temperature sensors are used?

- ☐ single sensor, without circulation
- ☐ single sensor, with circulation
- ☐ 2-4 sensors
- ☐ 5 or more sensors
- ☐ temperature-averaging probe

If product temperature is measured during a test, what type of temperature sensor is used?

- ☐ resistance temperature detector (RTD)
- ☐ bimetallic strip
- ☐ quartz crystal
- ☐ thermistor
- ☐ other (describe briefly) ____________________

If product temperature is not measured during a test, why not?

- ☐ the factor measured for change in level or volume is independent of temperature (e.g., mass)
- ☐ the factor measured for change in level or volume self-compensates for changes in temperature
- ☐ other (explain briefly) ____________________

Data Acquisition

How are the test data acquired and recorded?

- ☐ manually
- ☐ by strip chart
- ☐ by computer

Procedure Information

> Waiting times

What is the minimum waiting period between adding a large volume of product to bring the level to test requirements and the beginning of the test (e.g., from 50% to 95% capacity)?

- ☐ not applicable
- ☐ no waiting period
- ☐ less than 3 hours
- ☐ 3-6 hours
- ☐ 7-12 hours
- ☐ more than 12 hours
- ☐ variable, depending on tank size, amount added, operator discretion, etc.

> Test duration

What is the minimum time for collecting data?

- ☐ less than 1 hour
- ☐ 1 hour
- ☐ 2 hours
- ☐ 3 hours
- ☐ 4 hours
- ☐ 5-10 hours
- ☐ more than 10 hours
- ☐ variable

> Total time

What is the total time needed to test with this method?

(setup time plus waiting time plus testing time plus time to return tank to service)

__________hours__________minutes

> Other important elements of the procedure or method

List here any other elements that could affect the performance of the procedure or method (e.g., positive or negative ullage pressure, tracer concentration, distance between tank and sampling ports, etc.)

____

____

____

____

____

> Identifying and correcting for interfering factors

How does the method determine the presence and level of the ground water above the bottom of the tank?

- ☐ observation well near tank
- ☐ information from USGS, etc.
- ☐ information from personnel on-site
- ☐ presence of water in the tank
- ☐ other (describe briefly) ______________________________
- ☐ level of ground water above bottom of the tank not determined

How does the method correct for the interference due to the presence of ground water above the bottom of the tank?

- ☐ head pressure increased by raising the level of the product
- ☐ different head pressures tested and leak rates compared
- ☐ tests for changes in water level in tank
- ☐ other (describe briefly) ______________________________
- ☐ no action

Does the method measure inflow of water as well as loss of product (gallon per hour)?

- ☐ yes
- ☐ no

Does the method detect the presence of water in the bottom of the tank?

- ☐ yes
- ☐ no

How does the method identify the presence of vapor pockets?

- ☐ erratic temperature, level, or temperature-compensated volume readings
- ☐ sudden large changes in readings
- ☐ statistical analysis of variability of readings
- ☐ other (describe briefly) ______________________________
- ☐ not identified
- ☐ not applicable; underfilled test method used

How does the method correct for the presence of vapor pockets?

- ☐ bleed off vapor and start test over
- ☐ identify periods of pocket movement and discount data from analysis
- ☐ other (describe briefly) ______________________________
- ☐ not corrected
- ☐ not applicable; underfilled test method used

How does the test method determine when tank deformation has stopped following delivery of product?

- ☐ wait a specified period of time before beginning test
- ☐ watch the data trends and begin test when decrease in product level has stopped
- ☐ other (describe briefly) ______________________________
- ☐ no procedure
- ☐ not applicable, does not affect principle of operation

Are the method's sensors calibrated before each test?

- ☐ yes
- ☐ no

If not, how often are the sensors calibrated?

- ☐ weekly
- ☐ monthly
- ☐ yearly or less frequently
- ☐ never

> Interpreting test results

What effect is used to declare the tank to be leaking? (List all modes used by the method.)

____

____

____

____

If a change in volume is used to detect leaks, what threshold value for product volume change (gallon per hour) is used to declare that a tank is leaking?

- ☐ 0.05 gallon per hour
- ☐ 0.10 gallon per hour
- ☐ 0.20 gallon per hour
- ☐ other ______________________________

Under what conditions are test results considered inconclusive?

- ☐ ground-water level above bottom of tank
- ☐ presence of vapor pockets
- ☐ too much variability in the data (standard deviation beyond a given value)
- ☐ unexplained product volume increase
- ☐ other (describe briefly) ______________________

Exceptions

Are there any conditions under which a test should not be conducted?

- ☐ ground-water level above bottom of tank
- ☐ presence of vapor pockets
- ☐ large difference between ground temperature and delivered product temperature
- ☐ extremely high or low ambient temperature
- ☐ invalid for some products (specify) ______________________
- ☐ soil not sufficiently porous
- ☐ other (describe briefly) ______________________

What are acceptable deviations from the standard testing protocol?

- ☐ none
- ☐ lengthen the duration of test
- ☐ other (describe briefly) ______________________

What elements of the test procedure are left to the discretion of the testing personnel on-site?

- ☐ waiting period between filling tank and beginning test
- ☐ length of test
- ☐ determination of presence of vapor pockets
- ☐ determination that tank deformation has subsided
- ☐ determination of "outlier" data that may be discarded
- ☐ other (describe briefly) ______________________
- ☐ none

Reporting Form for Leak Test Results
Nonvolumetric Tank Tightness Testing Method

Instructions for completing the form

This 3-page form is to be filled out by the evaluating organization upon completion of the evaluation of the method in each of its leak detection modes. This form provides for 60 test results, although the minimum number of tests required in the protocol is 42. Use as many pages as necessary to summarize all of the tests attempted. Report the results for each leak detection mode on separate forms.

Indicate the commercial name and the version of the method and the period of evaluation above the table. The version is provided for methods that might use different versions of the equipment for different products or tank sizes. Also, indicate the leak detection mode for which these results were obtained.

In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for that form will consist of the field test results recorded by the evaluating organization's field crew on the Individual Test Logs and the vendor's test results.

The table consists of 10 columns. One line is provided for each test performed during evaluation of the method. If a test was invalid or was aborted, the test should be listed with the appropriate notation (e.g., invalid) on the line.

The **Test Number** in the first column refers to the test number from the randomization design determined according to the instructions in Section 6.2 of the protocol. Since some changes to the design might occur during the course of the field testing, the test numbers might not always be in sequential order.

Note that the results from the **trial run** need to be reported here as well.

The following list matches the column input required with its source, for each column in the table.

Reporting Form for Leak Test Results
Nonvolumetric Tank Tightness Testing Method

Instructions for completing the form

This 3-page form is to be filled out by the evaluating organization upon completion of the evaluation of the method in each of its leak detection modes. This form provides for 60 test results, although the minimum number of tests required in the protocol is 42. Use as many pages as necessary to summarize all of the tests attempted. Report the results for each leak detection mode on separate forms.

Indicate the commercial name and the version of the method and the period of evaluation above the table. The version is provided for methods that might use different versions of the equipment for different products or tank sizes. Also, indicate the leak detection mode for which these results were obtained.

In general, the statistician analyzing the data will complete this form. A blank form can be developed on a personal computer, the data base for a given evaluation generated, and the two merged on the computer. The form can also be filled out manually. The input for that form will consist of the field test results recorded by the evaluating organization's field crew on the Individual Test Logs and the vendor's test results.

The table consists of 10 columns. One line is provided for each test performed during evaluation of the method. If a test was invalid or was aborted, the test should be listed with the appropriate notation (e.g., invalid) on the line.

The **Test Number** in the first column refers to the test number from the randomization design determined according to the instructions in Section 6.2 of the protocol. Since some changes to the design might occur during the course of the field testing, the test numbers might not always be in sequential order.

Note that the results from the **trial run** need to be reported here as well.

The following list matches the column input required with its source, for each column in the table.

Column No.	Input	Source
1	Test number or trial run	Randomization design
2	Date at completion of last fill (if applicable)	Individual Test Log
3	Time at completion of last fill (if applicable)	Individual Test Log
4	Date test began	Individual Test Log
5	Time test began	Individual Test Log
6	Time test ended	Individual Test Log
7	Product temperature differential (if applicable)	Individual Test Log
8	Nominal leak rate	Randomization design
9	Induced leak rate	Individual Test Log
10	Leak test result	Vendor's test result

Note: the product temperature differential (column 7) is the difference between the temperature of the product added and that of the product in the tank each time the tank is filled. This temperature differential is the actual differential achieved in the field and not the nominal temperature differential.

Reporting Form for Leak Test Results
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________ Leak Detection Mode: ______________

Evaluation Period: from __________ to __________ (Dates)

Test No.	If applicable Date at Completion of Last Fill (m/d/y)	If applicable Time at Completion of Last Fill (military)	Date Test Began (m/d/y)	Time Test Began (military)	Time Test Ended (military)	If applicable Product Temperature Differential (deg F)	Nominal Leak Rate (gal/h)	Induced Leak Rate (gal/h)	Tank Tight? (Yes, No, or Test Invalid)
Trial Run						0	0	0	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

Reporting Form for Leak Test Results
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________________ Leak Detection Mode: ____________________

Evaluation Period: from ____________ to ____________ (Dates)

Test No.	If applicable Date at Completion of Last Fill (m/d/y)	If applicable Time at Completion of Last Fill (military)	Date Test Began (m/d/y)	Time Test Began (military)	Time Test Ended (military)	If applicable Product Temperature Differential (deg F)	Nominal Leak Rate (gal/h)	Induced Leak Rate (gal/h)	Tank Tight? (Yes, No, or Test Invalid)
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									
35									
36									
37									
38									
39									
40									

Reporting Form for Leak Test Results
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________ Leak Detection Mode: ______________

Evaluation Period: from __________ to __________ (Dates)

Test No.	If applicable Date at Completion of Last Fill (m/d/y)	If applicable Time at Completion of Last Fill (military)	Date Test Began (m/d/y)	Time Test Began (military)	Time Test Ended (military)	If applicable Product Temperature Differential (deg F)	Nominal Leak Rate (gal/h)	Induced Leak Rate (gal/h)	Tank Tight? (Yes, No, or Test Invalid)
41									
42									
43									
44									
45									
46									
47									
48									
49									
50									
51									
52									
53									
54									
55									
56									
57									
58									
59									
60									

Individual Test Log
Nonvolumetric Tank Tightness Testing Method

Instructions for completing the form

This 5-page test log form is to be filled out by the field crew of the evaluating organization. A separate form is to be filled out for each individual test including the trial run (at least 43.) The information on these forms is to be kept blind to the vendor during the period of evaluation of the method. Adaptations of the form may be made as needed to document the evaluation data.

The form consists of nine parts. These are:

1. Header information
2. General background information
3. Conditions before testing
4. Topping off records (if applicable)
5. For tracer methods only
6. Conditions at beginning of test
7. Conditions at completion of testing
8. Leak rate data
9. Additional comments, if needed
10. Data sheet for leak simulation for tracer methods
11. Data sheet for induced leak rate calibration

All items are to be filled out and the appropriate boxes checked. If a question is not applicable, then indicate so as "NA". The following provides guidance on the use of this form.

Header Information

The header information is to be repeated on all five pages, if used. If a page is not used, cross it out and initial it. The field operator from the evaluating organization needs to print and sign his/her name and note the date of the test on top of each sheet.

The test number is the number obtained from the randomization design. It is not the sequential running test number. If a test needs to be rerun, indicate the test number of the test being rerun and indicate that on the test log (e.g., Test No. 5 repeat).

General Background Information

Indicate the commercial name of the method. Include a version identification if the method uses different versions for different products or tank sizes. The vendor's recommended stabilization period (if applicable) has to be obtained from the vendor prior to testing. This is important since it will impact on the scheduling of the evaluation. All other items in this section refer to the test tank and product. Indicate the ground-water level at the time of the test.

Theoretically, this information would remain unchanged for the whole evaluation period. However, weather conditions could change and affect the ground-water level. Also, the evaluating organization could change the test tank.

Conditions Before Testing

Fill in all the blanks. If the information is obtained by calculation (for example the amount of water in the tank is obtained from the stick reading and then converted to volume), this can be done after the test is completed. Indicate the unit of all temperature measurements by checking the appropriate box.

Note that the term "conditioning" refers to all activities undertaken by the evaluating field crew to prepare for a test. As such, the term refers to emptying or filling the tank, heating or cooling product, and changing the leak rate. In some cases, all of the above is performed, in others, only one parameter might be changed. For tracers, "conditioning" refers to preparation of the tank for testing. It includes the determination of the time to wait between spiking and testing.

Topping Off Records (if applicable)

If this step is performed, fill in the appropriate blanks.

For Tracer Methods Only

Fill in the appropriate information. Follow the instructions and complete the form on page 4.

Conditions at Beginning of Test

The evaluation organization's field crew will have calibrated the leak simulation equipment prior to the test. All leak rate calibration data need to be documented using the form on pages 4 or 5, as appropriate. Refer to previous calibration if this has been done. Adapt the form as necessary.

Once the evaluating organization's field crew is ready with the induced leak rate simulation, and the vendor starts the actual testing, record the date and time that the vendor's test data collection starts. Also, indicate the product temperature at that time. Fill out the weather condition section of the form. Indicate the nominal leak rate which is obtained from the randomization design.

Conditions at Completion of Testing

Indicate date and time when the test is completed.

Again, stick the tank and record the readings and the amount of water in the tank. Record all weather conditions as requested.

Leak Rate Data.

This section is to be filled out by the evaluating organization's statistician or analyst performing the calculations. This section can therefore be filled out as the evaluation proceeds or at the end of the evaluation.

The nominal leak rate is obtained from page 2 (Conditions at Beginning of Test). It should be checked against the nominal leak rate in the randomization design by matching test numbers.

The induced leak rate is obtained from the simulation data reported by the evaluating field crew on page 4 or 5 of this form.

The test result is that obtained by the vendor for that test.

Give the mode being investigated on the line following the test answer if the method uses more than one mode of leak detection.

Additional Comments (if needed)

Use this page for any comments (e.g., adverse weather conditions, equipment failure, reason for invalid test, etc.) pertaining to that test.

Leak Simulation Form for Tracer Methods (page 4)

For tracer methods, use the form on page 4 to document and measure delivery of the carrier with the appropriate concentration of the tracer to the spiking ports. Indicate the tracer used and the concentration of tracer in the carrier in the appropriate spaces. Report the distances between spiking port and all sampling ports. Record the time and amount of material released in the spiking port to document the leak simulation for tracer methods. Use as many pages as needed.

Induced Leak Rate Calibration Form (page 5)

For acoustical methods, the form on page 5 may be used to calibrate the liquid flow through the simulator under a standard set of conditions. The induced leak rate is the rate at which the liquid will flow at a specified head or depth of product. This rate is determined by calibration and used as the leak rate for detection. The calibration will have to be done at a different time, preferably before) than the testing. A calibration is needed for each distinct leak rate. Once the calibrations have been done, document on each daily test log the simulation conditions and reference the appropriate calibration data sheets, which should be attached to the daily test log that first uses the given induced leak rate.

Name of Field Operator ______________________________

Signature of Field Operator ____________________ **Test No.** __________

Date of Test __________

Individual Test Log

Nonvolumetric Tank Tightness Testing Method

Instructions:
Use one log for each test.
Fill in the blanks and check the boxes, as appropriate.
Keep test log even if test is inconclusive.

General Background Information

Method Name and Version ______________________________

Product Type ______________________________

Type of Tank ______________________________

Tank Dimensions (nominal)

- Diameter ______ inches
- Length ______ inches
- Volume ______ gallons

Ground-water level ______ inches above bottom of tank

Recommended stabilization period before test (per vendor SOP)

______ hours ______ minutes

Conditions Before Testing

Date ________ and military time ________ at start of conditioning test tank

Stick reading before partial emptying of tank

- Product ______ inches ______ gallons
- Water ______ inches ______ gallons

Temperature of product in tank before partial emptying ______ °F ☐ or °C ☐.

Stick reading after partial emptying of tank

- Product ______ inches ______ gallons

Amount of product removed from tank (by subtraction) ______ gallons

Stick reading after filling tank to test level

- Product ______ inches ______ gallons
- Water ______ inches ______ gallons

Amount of product added to fill tank (by subtraction) ______ gallons

Name of Field Operator ______________________________

Signature of Field Operator ____________________ **Test No.** __________

Date of Test __________

Conditions Before Testing (continued)

Temperature of product added to fill tank ______ °F ☐ or °C ☐

Temperature of product in tank immediately after filling ______ °F ☐ or °C ☐

Date ________ and military time ________ at completion of fill

Topping Off Records (if applicable)

Date ________ and military time ________ at completion of topping off

Approximate amount of product added ______ gallons

If tank overfilled, height of product above tank ______ inches

For Tracer Methods Only

Date ________ and military time ________ tracer(s) is added to product in test tank

Tracer used ______________

Amount of tracer used ________

Amount of product in test tank ________ gallons

> Complete the Tracer Leak Simulation form (use page 4)

Date ________ and military time ________ at start of test

Date ________ and military time ________ at conclusion of test

Conditions at Beginning of Test

Date ________ and military time ________ vendor began setting up test equipment

> Document induced leak rate determination (use page 5)

Date ________ and military time ________ at start of vendor's test data collection

Temperature of product in tank at start of test ________ °F ☐ or °C ☐

Weather Conditions

Temperature ______ °F ☐ or °C ☐

Barometric pressure ______ mm Hg ☐ or ______ in. Hg ☐

Wind	None ☐	Light ☐	Moderate ☐	Strong ☐
Precipitation	None ☐	Light ☐	Moderate ☐	Heavy ☐
Sunny ☐	Partly Cloudy ☐		Cloudy ☐	

Nominal leak rate ______ gallon per hour

Name of Field Operator ______________________________

Signature of Field Operator ____________________ **Test No.** __________

Conditions at Completion of Testing

Date__________ and military time__________ at completion of test data collection

Stick reading at completion of test data collection

Product __________inches __________gallons

Water __________inches __________gallons

Date of Test ______________

Conditions at Completion of Testing (continued)

Weather Conditions

Temperature ________ °F ☐ or °C ☐

Barometric pressure ________mm Hg ☐ or ________in. Hg ☐

Wind None ☐ Light ☐ Moderate ☐ Strong ☐

Precipitation None ☐ Light ☐ Moderate ☐ Heavy ☐

Sunny ☐ Partly Cloudy ☐ Cloudy ☐

Date__________ and military time__________ test equipment is disassembled (if done for this test) and tank is ready for service

Leak Rate Data

Leak detection mode ______________________________

Nominal leak rate ________gal/h

Induced leak rate ________gal/h

Findings for Tracer Methods

☐ No tracer found ☐ Tracer(s) found

If tracer(s) found, list ______________________________

____

____

____

Test answer ☐ leaking ☐ tight ☐ inconclusive

Additional Comments (Use back of page if needed)

Name of Field Operator ______________________________

Signature of Field Operator ______________________________

Date of test ______________ Test No. ______________

Leak Simulation Form for Tracer Method

(Reproduce form if needed)

Tracer used ______________

Carrier ______________

Concentration of tracer in carrier ______________

Distance from spiking port to:

Sampling port 1 ________ Sampling port 5 ________

Sampling port 2 ________ Sampling port 6 ________

Sampling port 3 ________ Sampling port 7 ________

Sampling port 4 ________ Sampling port 8 ________

	Time (military)	Carrier amount released in spiking port	Comments
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Indicate all measurement units!

Name of Field Operator ______________________________

Signature of Field Operator ______________________________

Date of test ____________ Test No.____________

Induced Leak Rate Calibration Form

(Reproduce form if needed)

	Time (military)	Amount *	Comments
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

* *Indicate all measurement units!*

Reporting Form for Water Sensor Evaluation Data
Nonvolumetric Tank Tightness Testing Method

This 4-page form is to be filled out by the field crew of the evaluating organization when evaluating the performance of the method's water sensor, if applicable. A separate form is to be filled out for each individual test replicate (at least 20). The form provides a template to record the data and consists of three parts. These are:

1. Header information
2. Template for recording the data obtained to determine the minimum water level that the sensor can detect in each replicate (page 1)
3. Template for recording the data obtained when determining the minimum water level change that the sensor can detect in each replicate (pages 2-4).

Header Information

The header information is to be repeated on all four pages, if used. If a page is not used, cross it out and initial it.

Indicate the commercial name of the method. Include a version identification if the method uses different versions for different products or tank sizes. Complete the date of test and product type information. Indicate the test (replicate) number on each sheet for each test.

The field operator from the evaluating organization needs to print and sign his/her name and note the date of the test on top of each sheet.

Minimum Detectable Water Level Data

Follow the test protocol described in Section 6.5 and record all data on page 1 of the form. When the sensor first detects the water, stop testing for this replicate. The minimum detected water level is calculated from the total amount of water added until the first sensor response and the geometry of the probe and the cylinder. This calculation can be done after all testing is completed and is generally performed by the statistician or other person responsible for data analysis.

Minimum Detectable Water Level Change

After the first sensor response, continue with the test protocol as described in Section 6.5. Record all amounts of water added and the sensor readings at each increment using pages 2 to 4 as necessary. The data to be entered in the third, fifth, and sixth columns on pages 2, 3, and 4 of the form will be calculated once all testing is completed. Again, the person responsible for the data analysis will generally compute these data and enter the calculated minimum water level detected in that replicate run.

Reporting Form for Water Sensor Evaluation Data
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________________

Date of Test: ____________________ Name of Field Operator: ____________________

Product Type: ____________________ Signature of Field Operator: ____________________

Test No. ___

Increment No.	Volume of Water Added (mL)	Sensor Reading (inch)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
Total Volume (mL)		

Calculated Minimum Detectable Water Level (inches)

NOTE: This form provides a template for data reporting. Since the number of increments is not known from the start, the length of the report form will vary from test to test.

Reporting Form for Water Sensor Evaluation Data
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________________

Date of Test: ____________________ Name of Field Operator: ____________________

Product Type: ____________________ Signature of Field Operator: ____________________

Test No. ___

Increment No. A	Volume of Water Added (mL) B	Calculated Water Height Increment, h (in) C	Sensor Reading (in) D	Measured Sensor Increment (in) E	Increment Difference Calc.–Meas. (in) C – E
Minimum water level detected, X:			inches (from page 1)		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					

NOTE: This form provides a template for data reporting. Use as many pages as necessary.

Reporting Form for Water Sensor Evaluation Data
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________________

Date of Test: ________________ Name of Field Operator: ________________

Product Type: ________________ Signature of Field Operator: ________________

Test No. ___

Increment No. A	Volume of Water Added (mL) B	Calculated Water Height Increment, h (in) C	Sensor Reading (in) D	Measured Sensor Increment (in) E	Increment Difference Calc.–Meas. (in) C – E
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					

NOTE: This form provides a template for data reporting. Use as many pages as necessary.

Reporting Form for Water Sensor Evaluation Data
Nonvolumetric Tank Tightness Testing Method

Method Name and Version: ______________________________

Date of Test: ________________ Name of Field Operator: ________________

Product Type: ________________ Signature of Field Operator: ________________

Test No. ___

Increment No. A	Volume of Water Added (mL) B	Calculated Water Height Increment, h (in) C	Sensor Reading (in) D	Measured Sensor Increment (in) E	Increment Difference Calc.–Meas. (in) C – E
51					
52					
53					
54					
55					
56					
57					
58					
59					
60					
61					
62					
63					
64					
65					
66					
67					
68					
69					
70					
71					
72					
73					
74					
75					

NOTE: This form provides a template for data reporting.
Use as many pages as necessary.